SnowEx: a NASA airborne campaign leading to a snow satellite mission

Community webex 4/13/17
First summary of Year 1 winter deployment (February) activities

Agenda

- Introduction
- Summary of airborne activities
- Summary of ground truth activities
- Summary of ground-based remote sensing (GBRS) activities
- Ancillary data, met data, satellite data
- Press coverage
- Data delivery plans
- Meetings & outreach
- Year 1 wrap-up activities
- Opportunities & Comments from Jared
- Summary of major year 1 accomplishments
- Concluding remarks

SnowEx: a Multi-Sensor Airborne Snow Campaign

SnowEx -- a multi-year airborne snow campaign designed to collect multi-sensor observations and ground truth, to enable algorithm development and modeling to inform the design of a future NASA global snow satellite mission

Key Questions:

- What is the global distribution of SWE, and snow energy balance, in a variety of land covers and canopy types & densities? Year 1 focus on forest.
- What are the sensitivity and accuracy of *individual* remote-sensing techniques to measure SWE across a variety of snow conditions & confounding factors?
- What is the best combination (multi-sensors and with models) of sensing methods to measure SWE globally?

Measurement Requirements

SWE accuracy: 2cm (SWE <20cm), 10% (SWE >20cm)

- Snow density accuracy: 20 kg/m^3 or 2%
- Snow depth accuracy: 3 cm
- Snow temperature: 1°C.
- Snow grain size: 0.2 mm (<1 mm), 1 mm (1-15 mm)

Year 1: Challenge snow remote-sensing techniques + models with forested environments

Airborne measurement techniques: passive & active microwave; passive & active VIS/IR, thermal IR

The path to today

- 14 yrs ago… the last big snow community campaign – CLPX-1
- 2.5 yrs ago…SnowEx announced at AGU
- 2 yrs ago…1st SnowEx workshop (May 2015, Columbia MD)
- 1.3 yrs ago...serious prep started
- 1 yr ago (March 2016)…Seattle meeting
  - No site selected, Primary aircraft not known
- 11 months ago (May 2016) …sites selected
- 9 months ago (July 2016) …major aircraft decided; LSOS identified
- 6 months ago (Sep/Oct) …first airborne & ground truth obs (no snow lidar background), met stations, GBRS begun
- 4 months ago (Nov 2016) …winter participant selection was still in process
- 1.5 months ago (Feb 2017)…..main winter campaign

Airborne

Year 1 Airborne Sensors

CONFIRMED CORE SENSORS

• SnowSAR: X & Ku-band radar (ESA)
• CAR (BRDF from GSFC)
• AESMIR (passive mw, from GSFC) 18 & 36 GHz (did not fly)
• Thermal IR/video suite
  • Imager (GSFC)
  • High-accuracy non-imaging (KT.15, from U.Washington)
  • Video camera (GSFC)
	NRL P-3

• ASO suite (JPL)
  • Lidar
  • Hyperspectral imager
	King Air

CONFIRMED EXPERIMENTAL SENSORS

• UAVSAR: L-band radar (JPL) • GLISTIN-A: Ka-band radar (JPL)	Two NASA G-IIIs

Prototype sensor

• WISM: X, Ku, & Ku-band radar (GSFC)	Twin Otter

SnowEx Aircraft

SnowEx Aircraft Sortie Summary

Aircraft	Instruments	# Sorties	FEBRUARY																											
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
P-3	SnowSAR, CAR, IR Suite (AESMIR)	6															1	1		1		1	1	1						
TOI	WISM	3								1	1	1																		
King Air	ASO	6								1								1				2	1				1			
G III (AFRC)	GLISTIN-A	4									1											1	1				1			
G III (JSC & AFRC)	UAVSAR	3						1																1			1			

Corrected to show only science flights over SnowEx sites.

Aircraft Summary: P-3

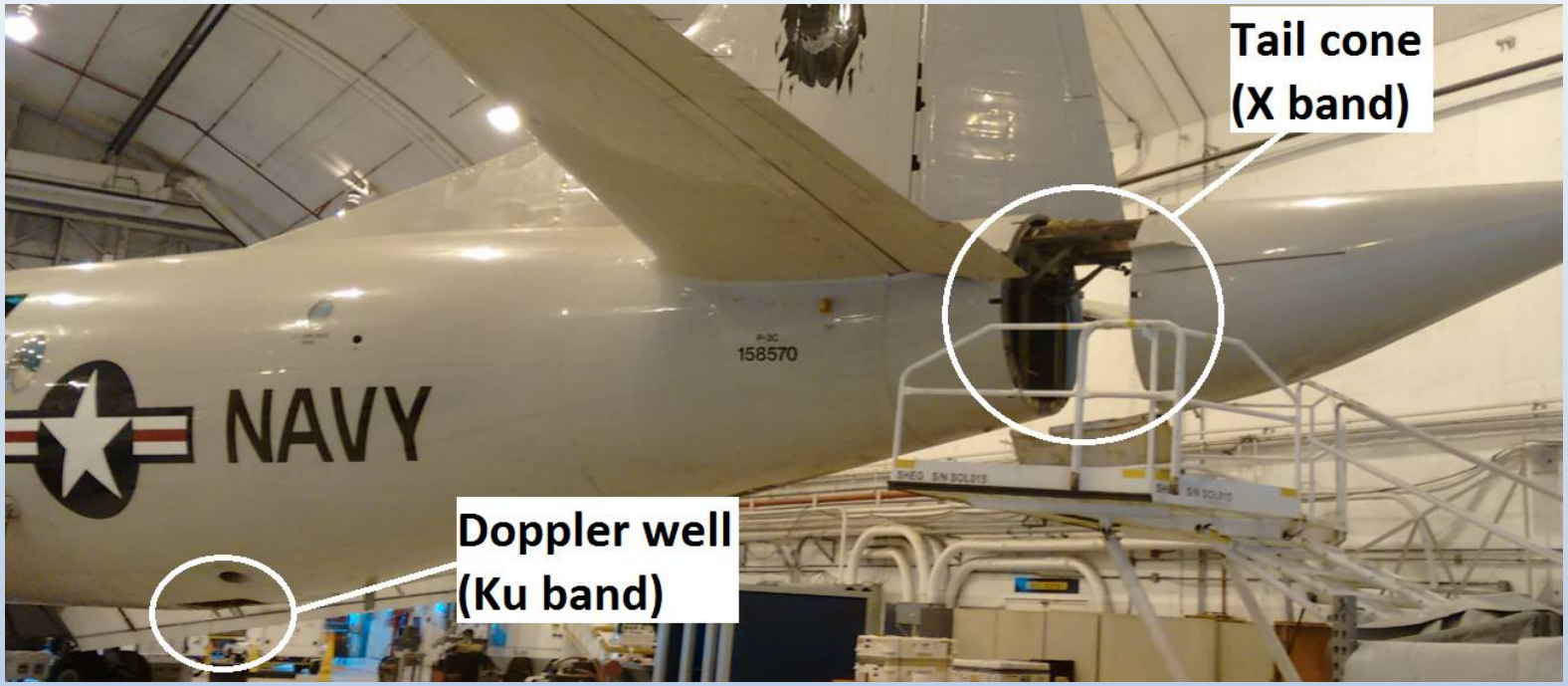
NRL P-3:

- support from the aircrew was exceptional.
- The aircraft had a few issues in the field, as is expected of older aircraft.
- Successfully accommodated flight changes while in the air multiple times

Summary of flights

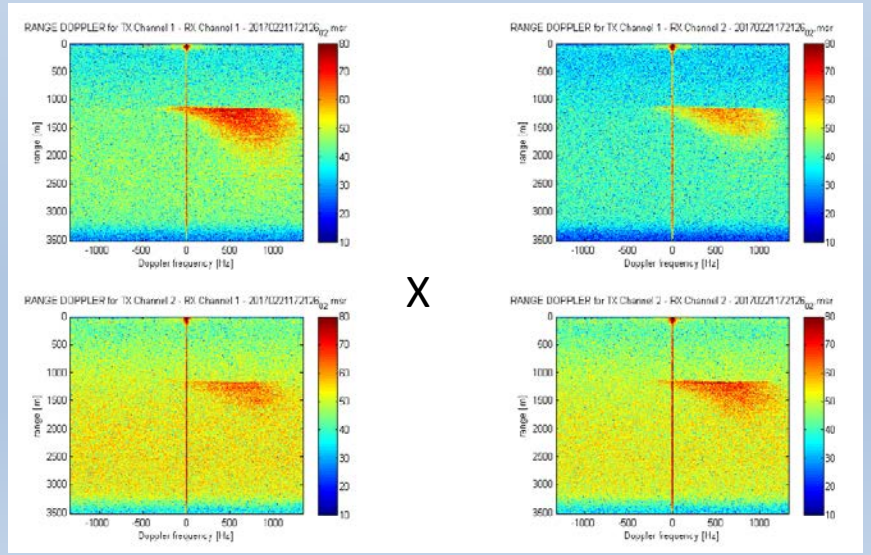
- Feb 15: P-3 arrival in Peterson AFB, Colorado Springs
- Feb 16: First science flight complete (4.4 hours) over Fraser Forest (FF), Grand Mesa (GM), and Senator Beck (SB) sites
- Feb 18: 2nd science flight (3.7 hours) to FF and GM
- Feb 20: 3rd science flight (4.0 hours) to FF and GM. RTB early due to SnowSAR inop
- Feb 21: 4th science flight (5.8 hours) to FF, GM, SB. No CAR data over GM due to cloud coverage.
- Feb 22: 5th science flight (5.0 hours) RTB early SnowSAR inop
- Feb 25: Cracked windshield prevented further science flights
- Mar 4: P-3 returned to Pax River

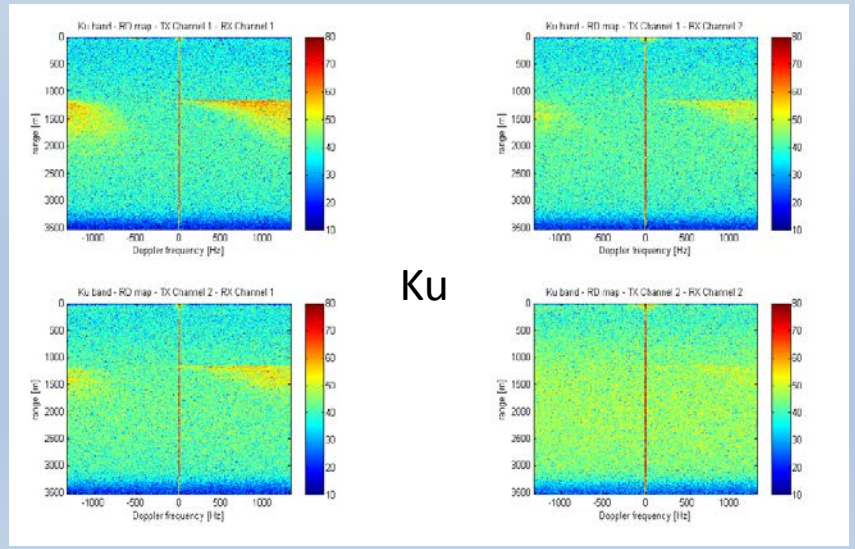
SnowSAR photos



SnowSAR Summary

- Campaign begun without check out flight at Pax River
- Some issues investigated/solved during actual science flights
  - Overall low SNR shown from results of first flights over GM suggesting lower flight altitude w.r.t. planned one
  - One pol channel more noisy than other at X band
  - Low returns at Ku band
  - Firmware bug
- Campaign over when SnowSAR was tuned up
- Available limited amount of tracks with full data (X and Ku, all pol channels), mainly during 1 day
- Preliminary analysis of the acquired data still in process
- Estimated delivery of processed images by end of May 2017

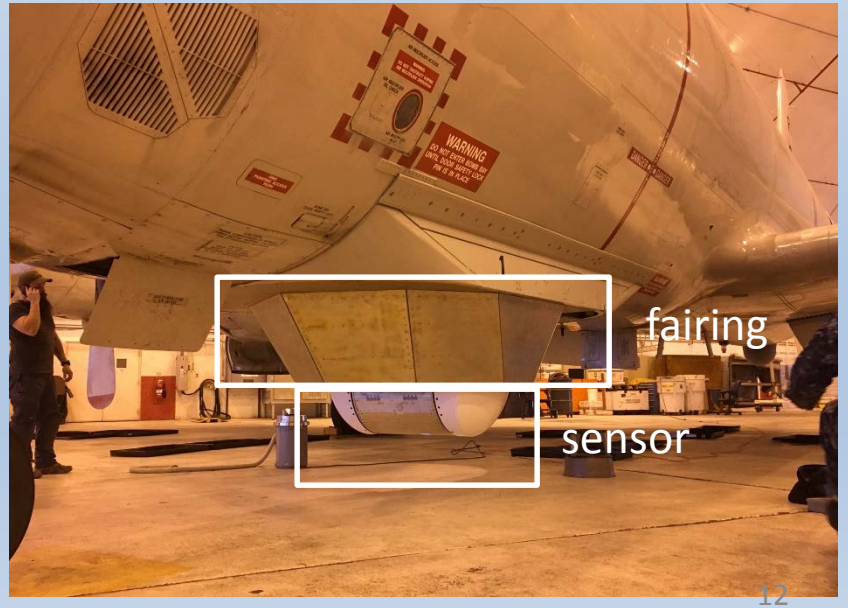




AESMIR Summary

- The AESMIR instrument itself was cleared to fly and has flown before
  - Instrument was fit-checked on aircraft and successfully operated on the ground
  - All systems were fully functional
- The aerodynamic fairing for the instrument was not cleared to fly
- Removed from aircraft to allow other P-3 instruments to go make SnowEx observations

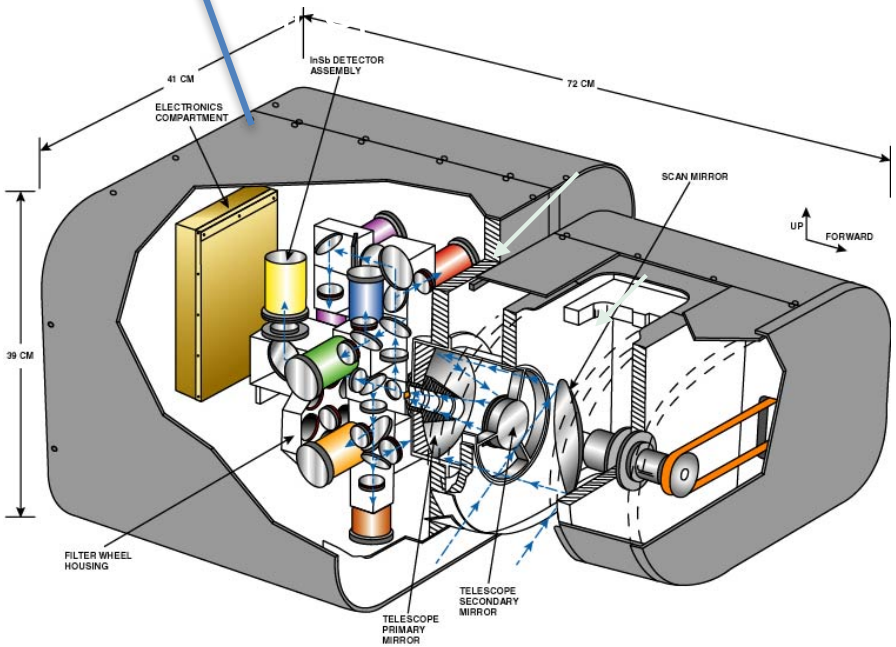
Control Rack



Overview of the CAR Instrument

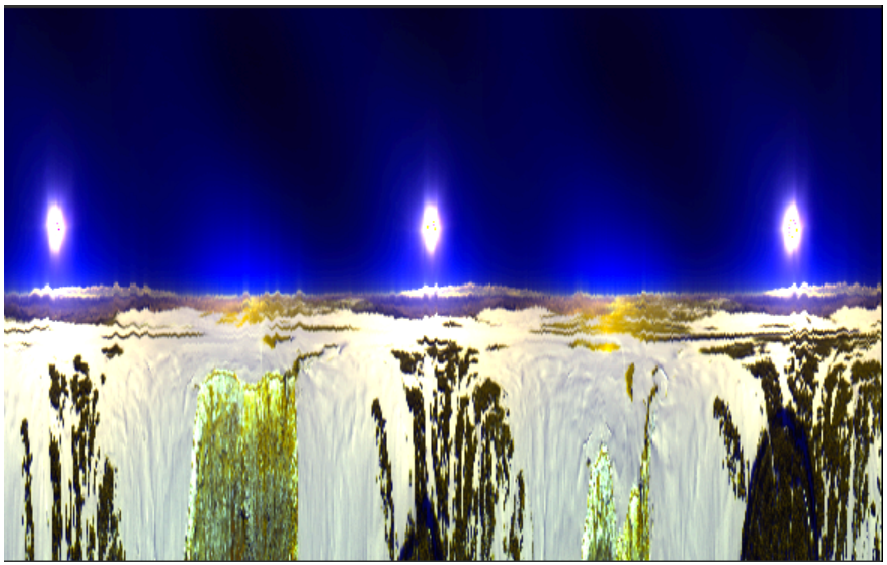
Sensor Characteristics:

- 14 spectral bands (0.34 to 2.29 μm)
- scan ±95° from horizon on right-hand side of aircraft or image 190° horizon-to-horizon
- field of view 17.5 mrad (1 deg.)
- scan rate 1.67 Hz (100 rpm)
- data system 9 channels @ 16 bit
- 395 pixels in scan line
- Platform: NRL P-3B

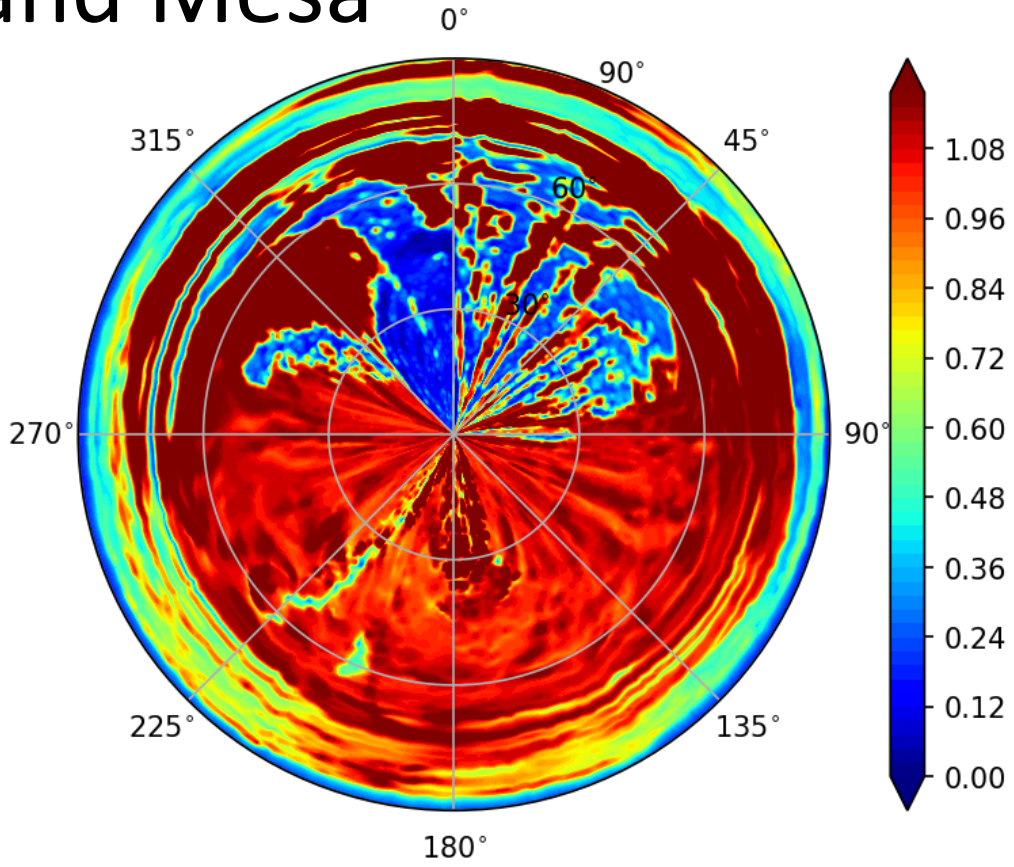


https://car.gsfc.nasa.gov/

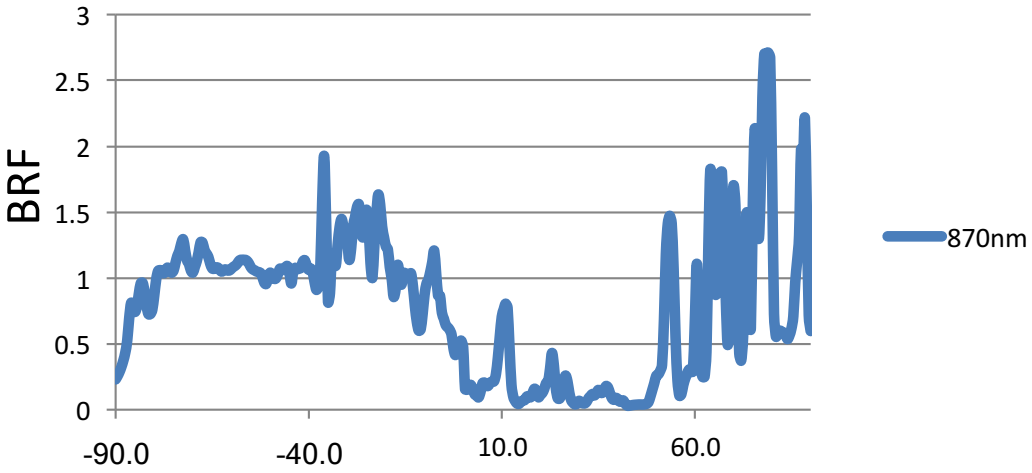
CAR/BRDF Meas.: Grand Mesa



22:47:00UTC - 22:53:00 UTC



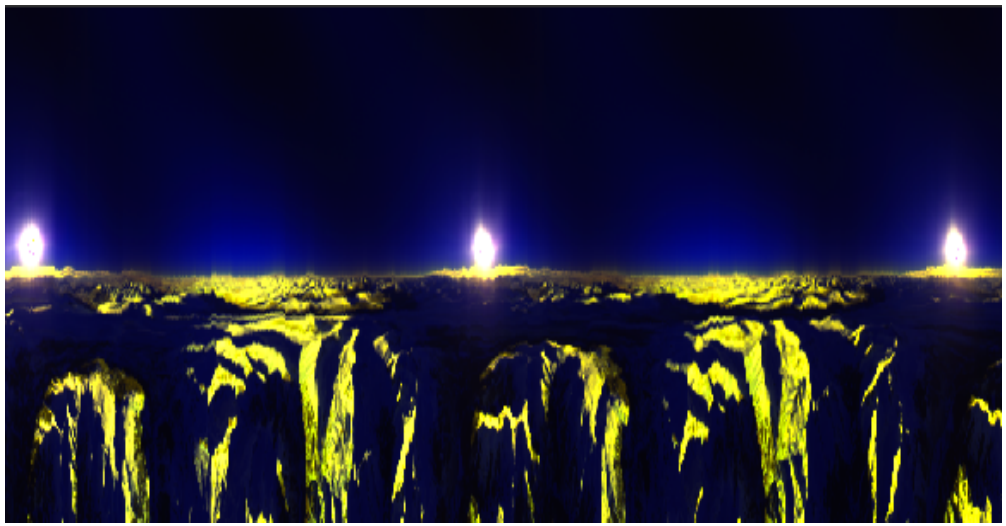
Principle Plane: 870 nm



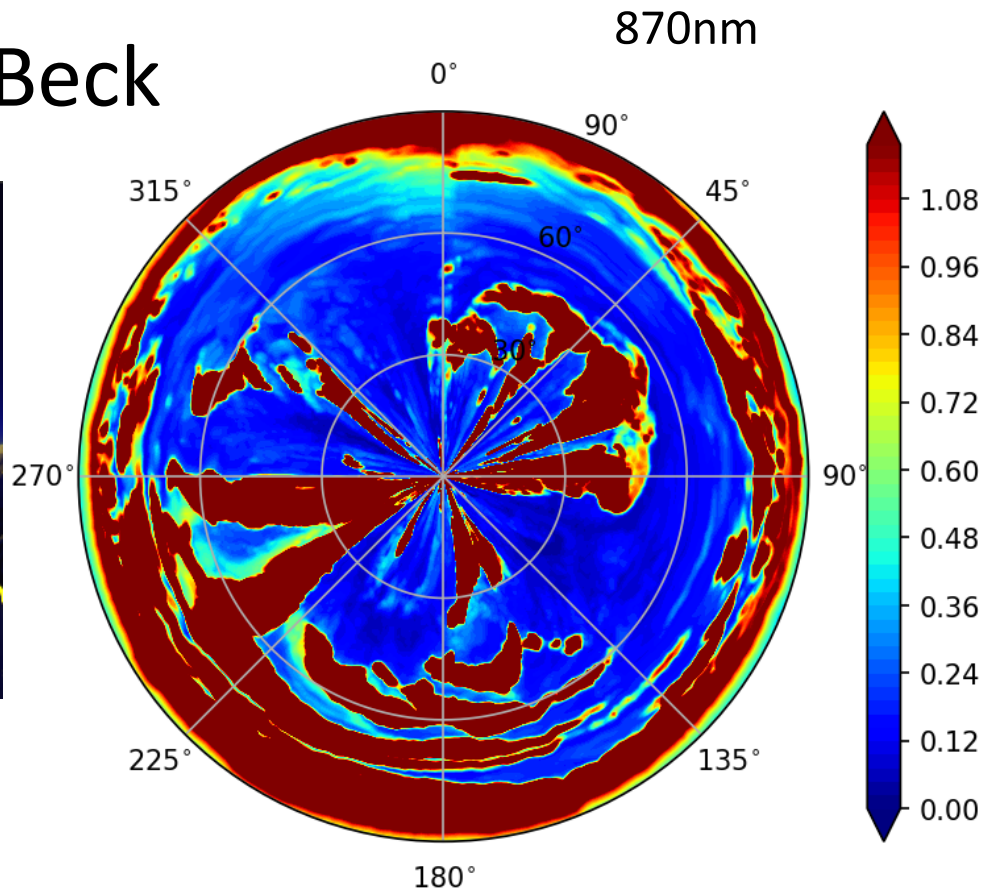
SZA = 73.70 deg.

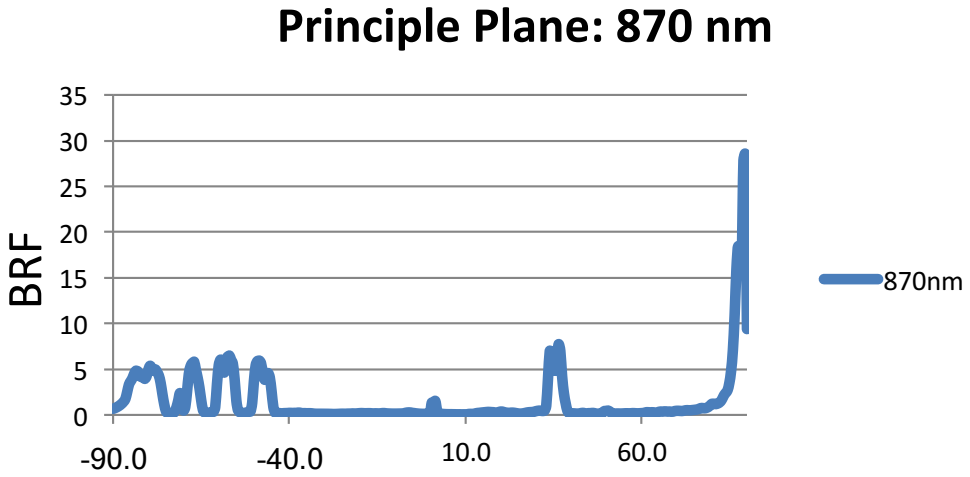
Feb 16, 2017

CAR/BRDF Meas.: Senator Beck



00:03:00 UTC - 00:12:00 UTC



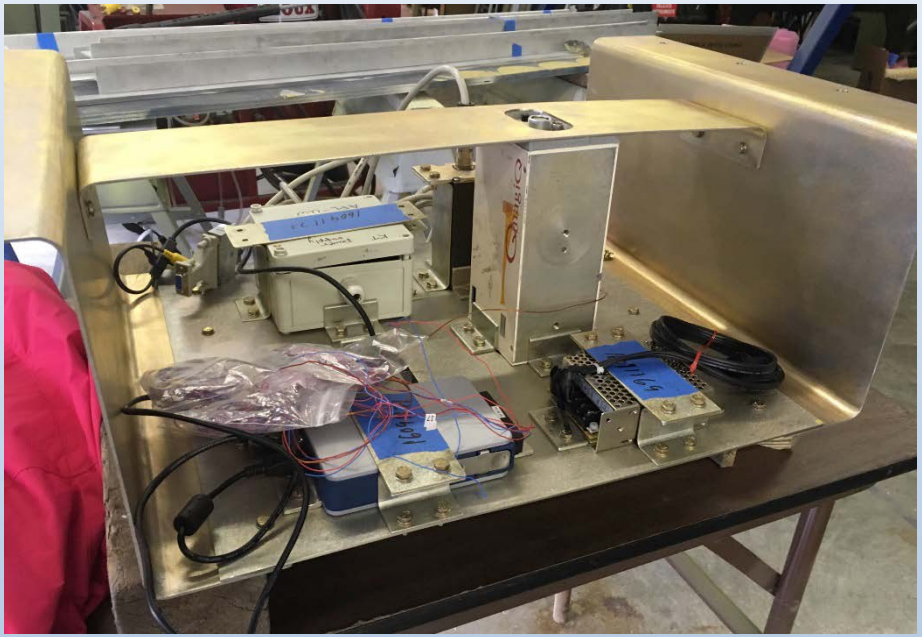


SZA = 86.03 deg.

Feb 16, 2017

P-3 Thermal IR Sensor Suite

- IR Sensor Suite consists of two instruments and a camera
  - QWIP infrared imager
  - KT-15 infrared thermometer
  - HD visual video camera
- All instruments point nadir through germanium/glass windows
- Windows, ambient, and instrument temperatures logged with thermocouples
- IRSS Instruments were cross-calibrated with ground team field IR targets before deployment
- IRSS Instruments calibrated with handheld target before/after each flight



P-3 Nadir Camera View

ASO flying during SnowEx

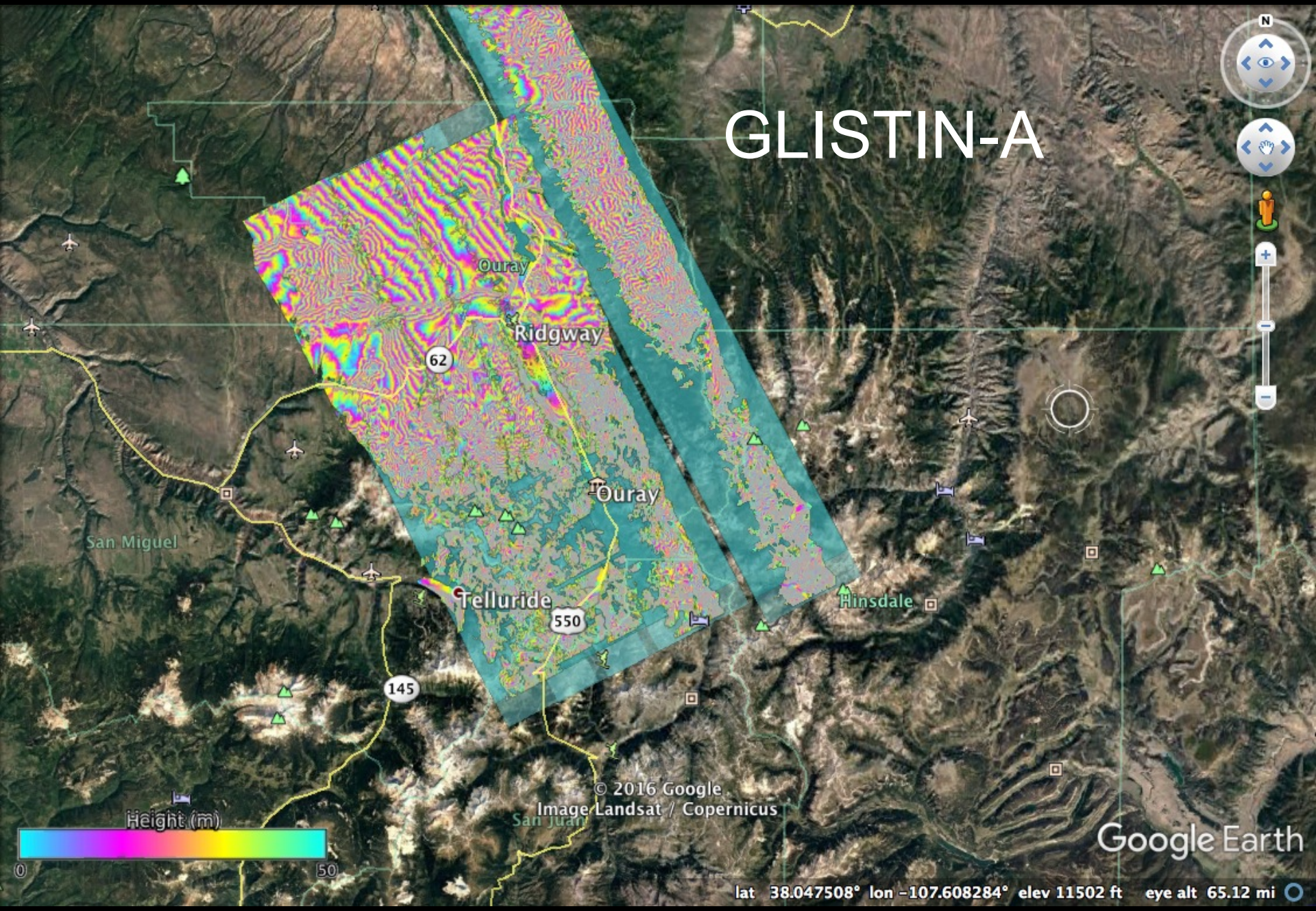
DATE	BASINS FLOWN	DURATION
2/8/2017	Grand Mesa, Senator Beck	05:00
2/16/2017	Grand Mesa, Senator Beck	04:24
2/20/2017	Senator Beck	02:01
2/20/2017	Grand Mesa	01:17
2/21/2017	Senator Beck, Grand Mesa	02:45
2/25/2017	Senator Beck, Grand Mesa	04:01

GLISTIN-A and UAVSAR flying during SnowEx

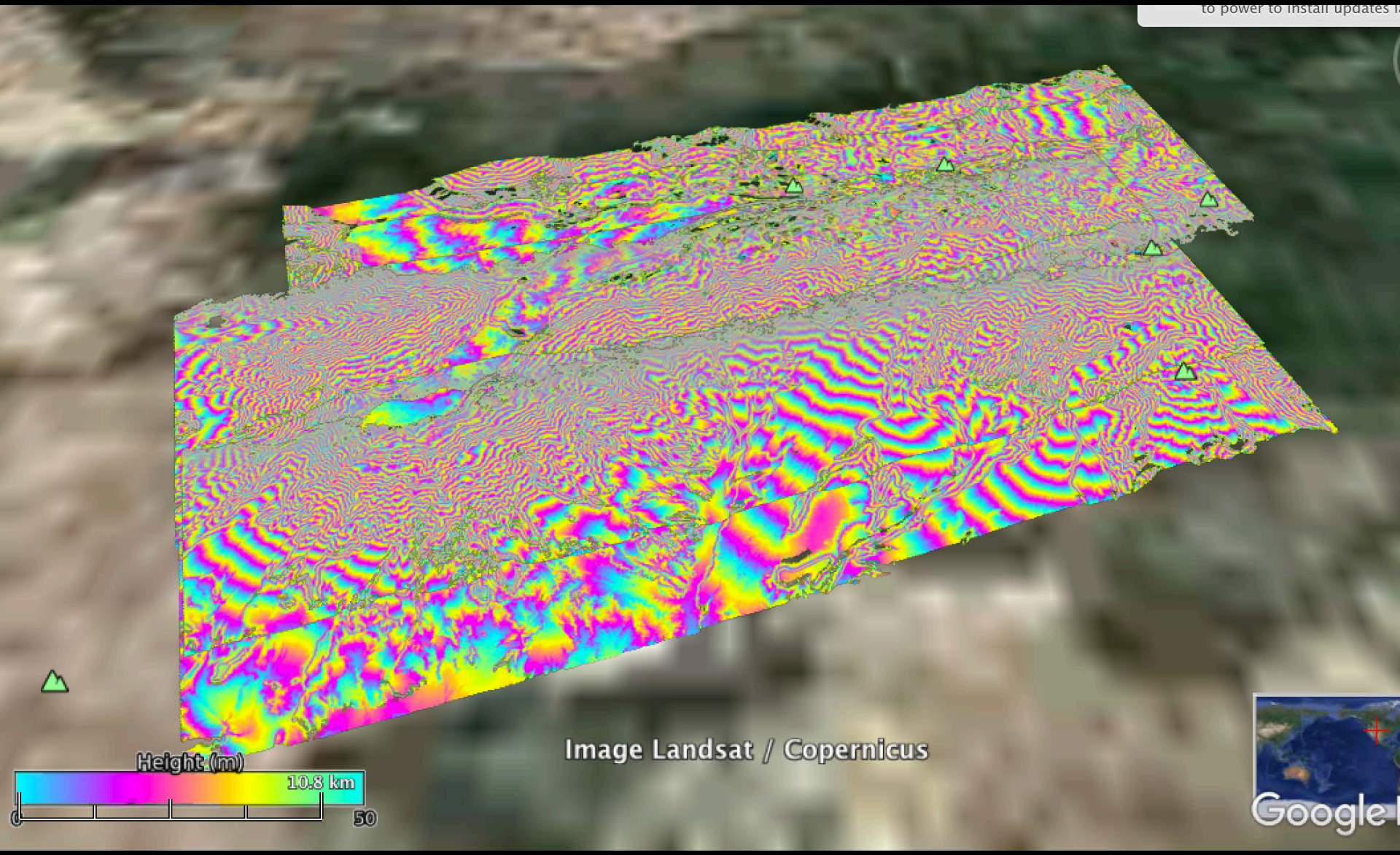
GLISTIN-A	UAVSAR
	February 6, 2017
February 9, 2017	
February 20, 2017	
February 21, 2017	
	February 22, 2017
February 25, 2017	February 25, 2017

- Snow depth retrieval – (*Moller et al.*, 2017)
- Leveraging ASO legacy for unique distributed SWE mapping and integration (240 flights)
- Insensitive to liquid water

- Differential interferometry (*Deeb et al.*, 2009; 2011; in prep)
- Ultimate NISAR retrieval
- Killed by liquid water


GLISTIN-A
Ouray
Ridgway
62
Ouray
San Miguel
Telluride
550
Hinsdale
145
San Juan
© 2016 Google
Image Landsat / Copernicus
Height (m)
0
50
Google Earth
lat 38.047508° lon -107.608284° elev 11502 ft eye alt 65.12 mi

Grand Mesa – GLISTIN-A



UAVSAR support for SnowEx

Mission Details

- L-Band (~ 1 GHz / 24 cm)
- Interferometric radar acquisitions
- SnowEx funding for 3 flights with 6 flight lines per flight (Feb 2017)
- NISAR SDT funding to continue collections (~ 3) after SnowEx
- SnowEx collection dates: Feb. 6, 22, 25
- **Analysis:** change in phase between acquisitions is related to the integrated snow depth/density (SWE)

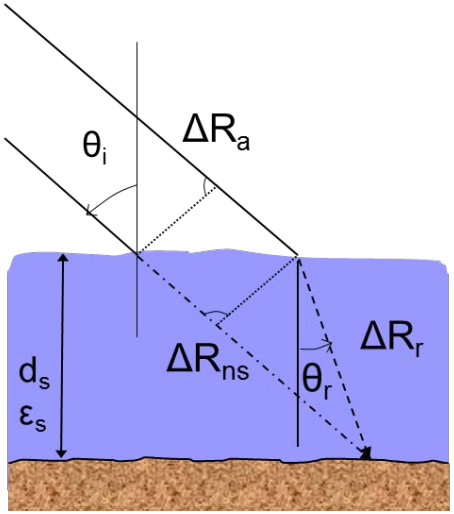


Figure 1. Idealized radar propagation: through atmosphere (ΔR_{ns}) and through snow ($\Delta R_a + \Delta R_r$) (modified from Guneriussen et al., 2001).

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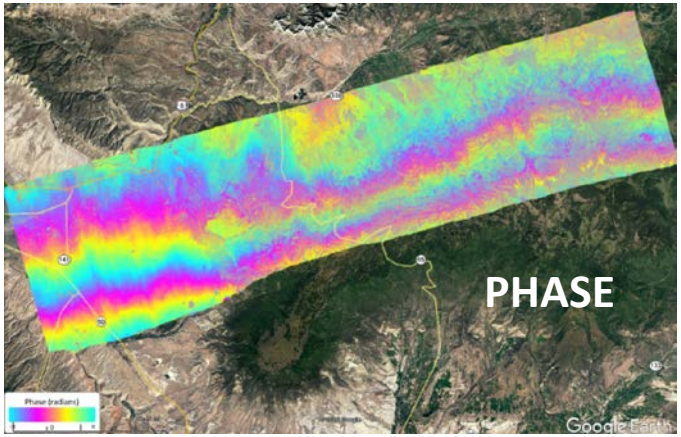
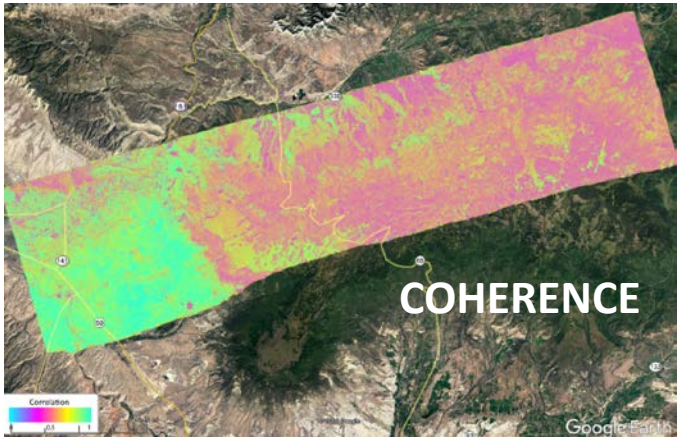
UAVSAR Grand Mesa Results

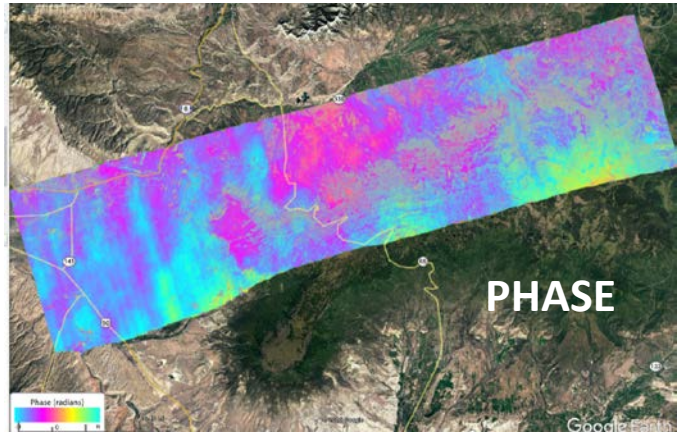
preliminary

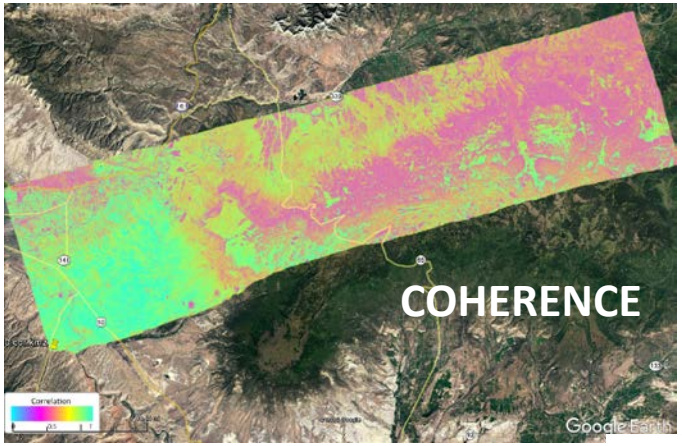
InSAR results for Feb 6 – 22





InSAR results for Feb 22 - 25





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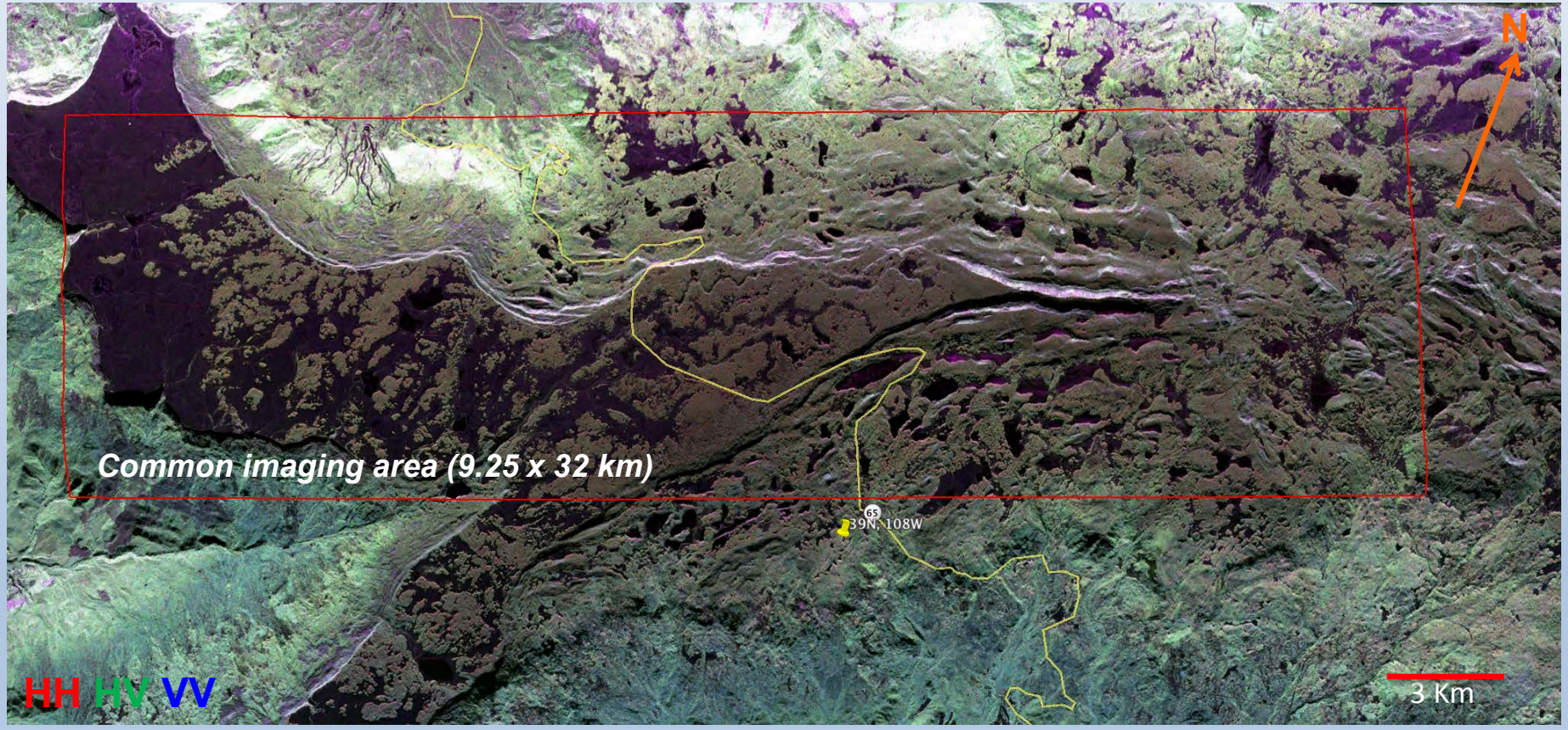
UAVSAR Polarimetric Image over Grand Mesa, Colorado

SnowEx Experiment in February 2017

- **UAVSAR flight aboard the JSC G-III on February 6, 2017 – successfully acquired 6 flight lines over Grand Mesa, Telluride (Senator Beck Basin), and Slumgullion respectively.**
- **Next UAVSAR flight is scheduled for February 20 aboard the AFRC C-20A jet, weather permitting.**



Preliminarily calibrated PolSAR image over Grand Mesa's common study area

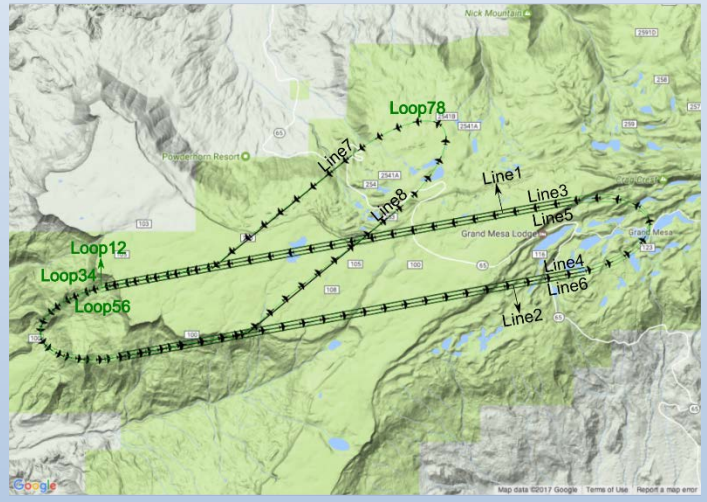
Wideband Instrument for Snow Measurements (WISM)

- Radar bands
  - 9.6, 13.6, 17.2 GHz (V-pol transmit/V&H receive)
  - Calibration via loop back and corner reflectors
- Radiometer bands
  - 10.6, 17.2, 36 GHz (H-pol)
  - Calibration via internal references, thru feed noise injection, pre- & post flight sky/box measurements
- Seven sorties flow (Feb 3 – 10)
  - 2 flights over Grand Mesa
- Radar and radiometer data processing underway. Data delivery due May 24 (IIP final review).

WISM installed on the Twin Otter

WISM Campaign #3 – Flight Summary

FL #	Date	Status	Hrs	Notes
1	02/03/17	Radar Only	0.8	Engineering Test Flight around **airport**/normal operation
2	02/05/17	Radar Only	0.8	Engineering Test Flight around **airport**/*no data collected*
3	02/05/17	Radar Only	0.7	Engineering Test Flight around **airport**/normal operation
4	02/06/17	Radar & Radiometer	0.8	Engineering Test Flight around **airport**/normal operation
5	02/08/17	Radar & Radiometer	0.5	Science flight over **Grand Mesa** *terminated due to radar problem*
6	02/09/17	Radar & Radiometer	1.9	Science Flight over **Grand Mesa**/ normal operation
7	02/10/17	Radar Only	1.7	Science Flight over **Grand Mesa**/ normal operation



Grand Mesa Flight Lines: Three loops staggered and dog leg run over auxiliary (boom truck) site

SnowEx Ground Measurements

*** Winter Campaign ***

Teams

Science

Kelly Elder
Ludovic Brucker
Chris Hiemstra
Hans-Peter Marshall

Logistics

Jerry Newlin
Mark Thomas
Tim Niemeyer
Joann Collins

Teams

Most importantly – all of you!

Ground Campaign Objectives

- Complete work safely
  - No accidents!

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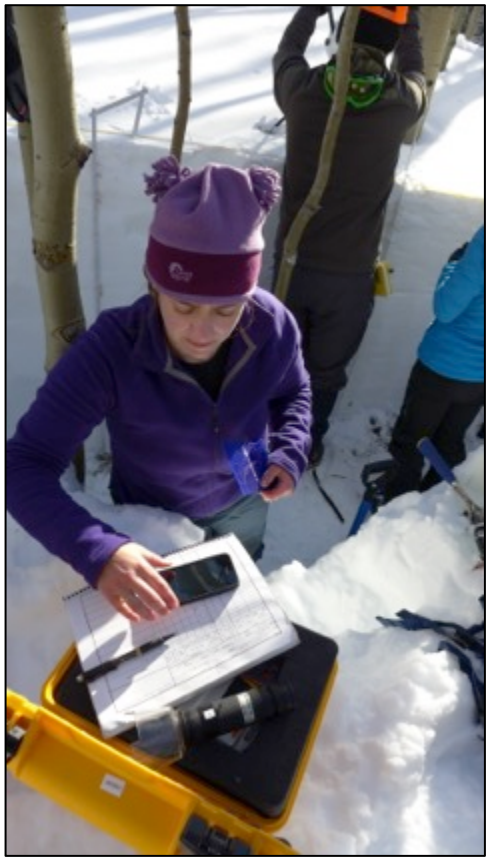
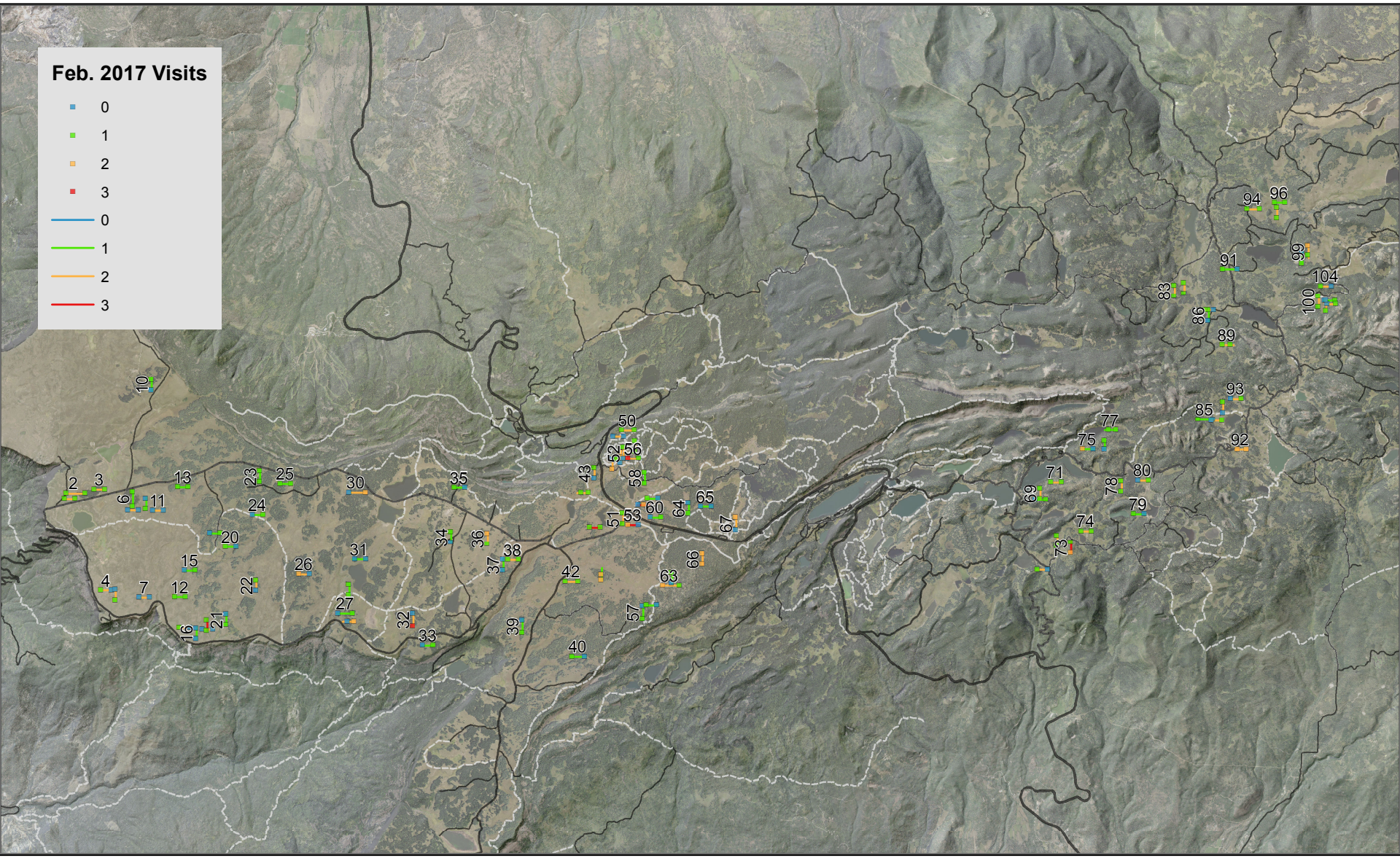
- Collect high-quality, relevant data
  - Looks mostly good – time will tell

Ground Campaign Objectives

- Complete work safely
  - No accidents!
- Collect high-quality, relevant data
  - Looks good – time will tell
- Educate and train community
  - Approximately 100 people participated!

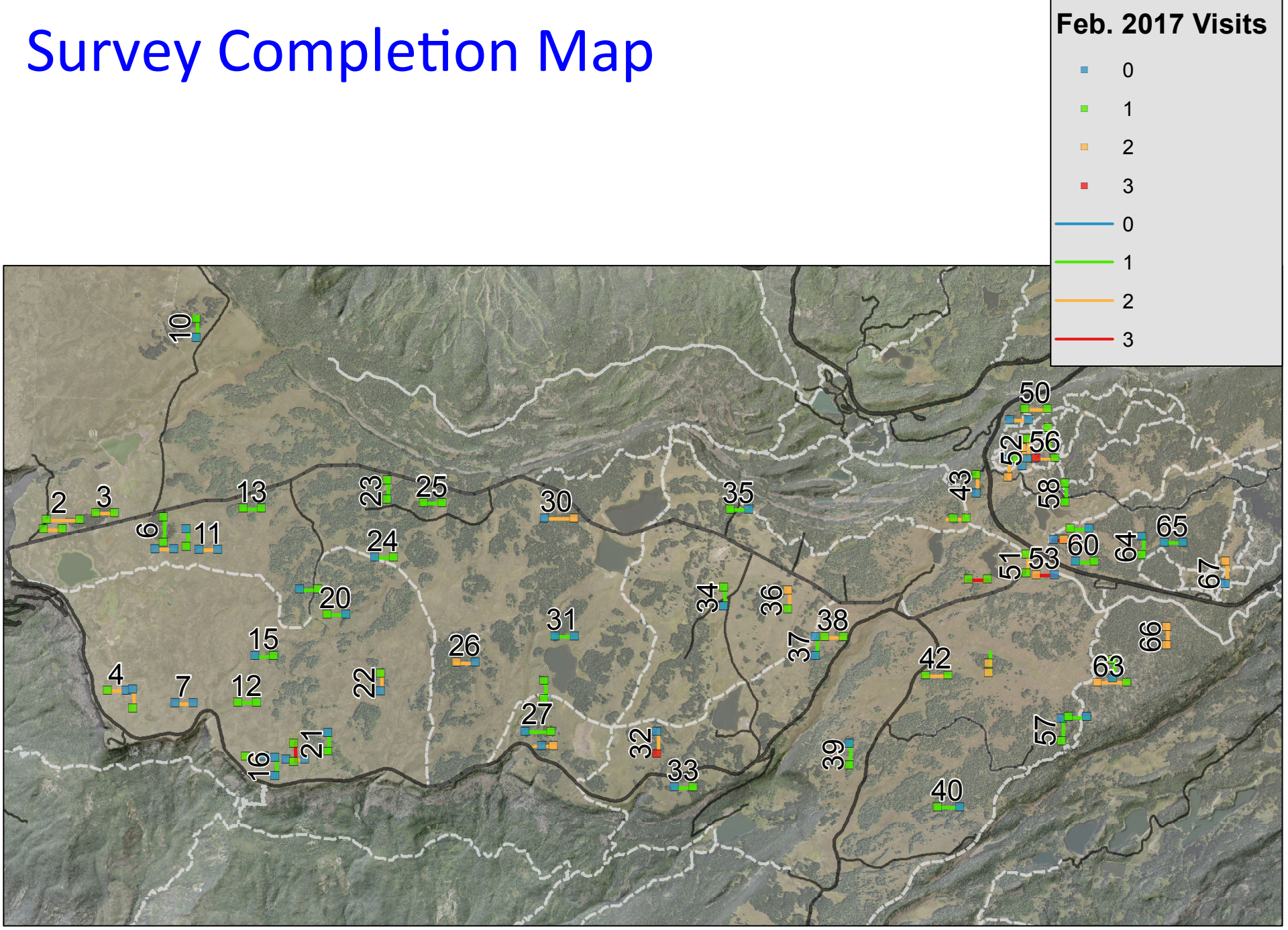


Survey Completion Map



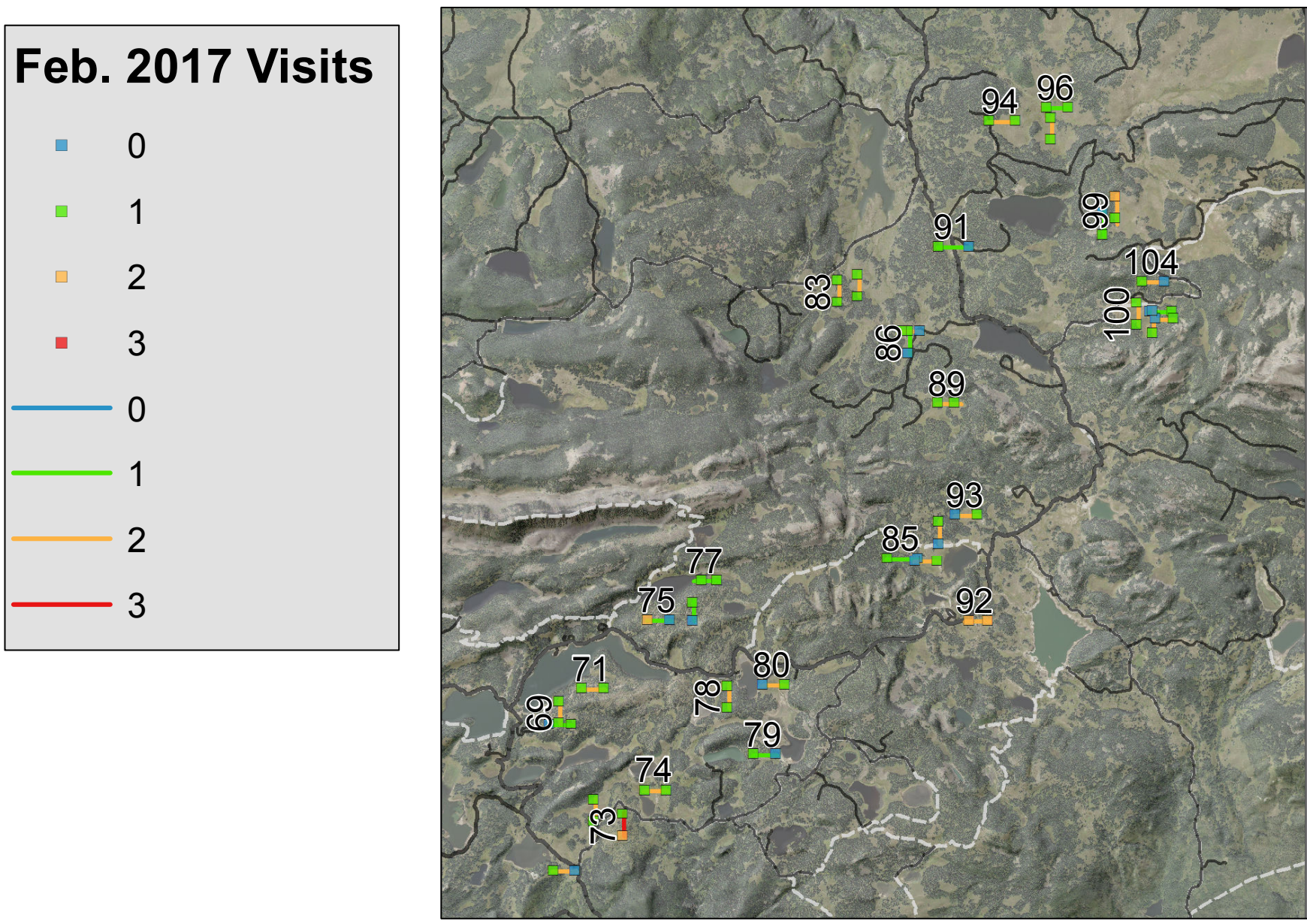
Graphics, mapping and GIS analytics by Chris Hiemstra

Survey Completion Map



Graphics, mapping and GIS analytics by Chris Hiemstra

Survey Completion Map



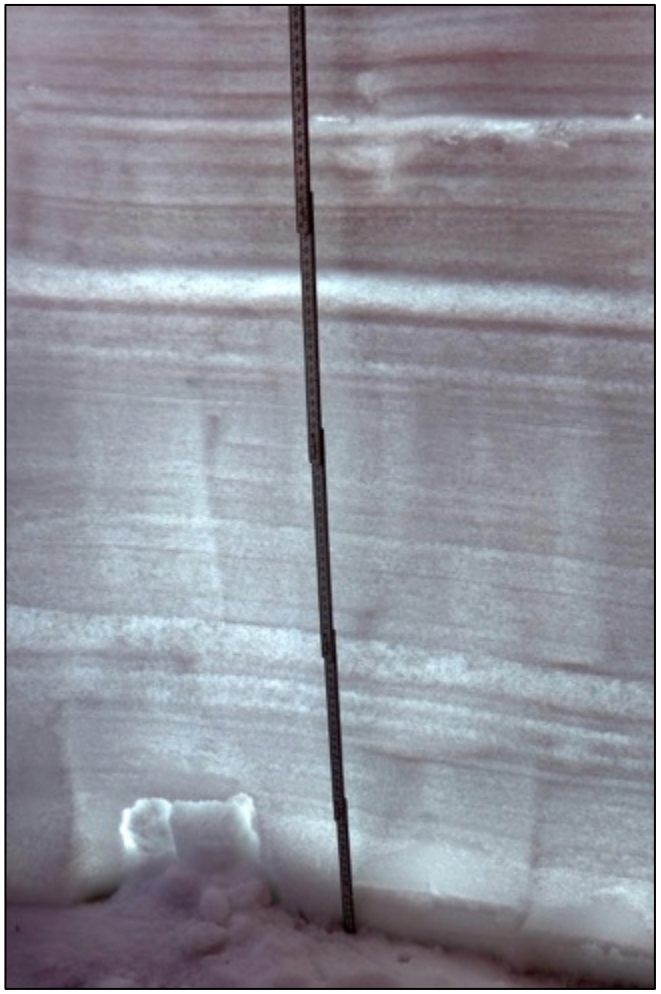
Graphics, mapping and GIS analytics by Chris Hiemstra

Standard Measurements

- 165 Snow Depth Transects
  - Loosely translates to 16,500 depth measurements!

Standard Measurements

- 154 Snow Pits
  - Loosely translates to ~4500 density measurements



Ground Based Remote Sensing (GBRS)

Overview of the SnowEx 2017 Ground Based Remote Sensing

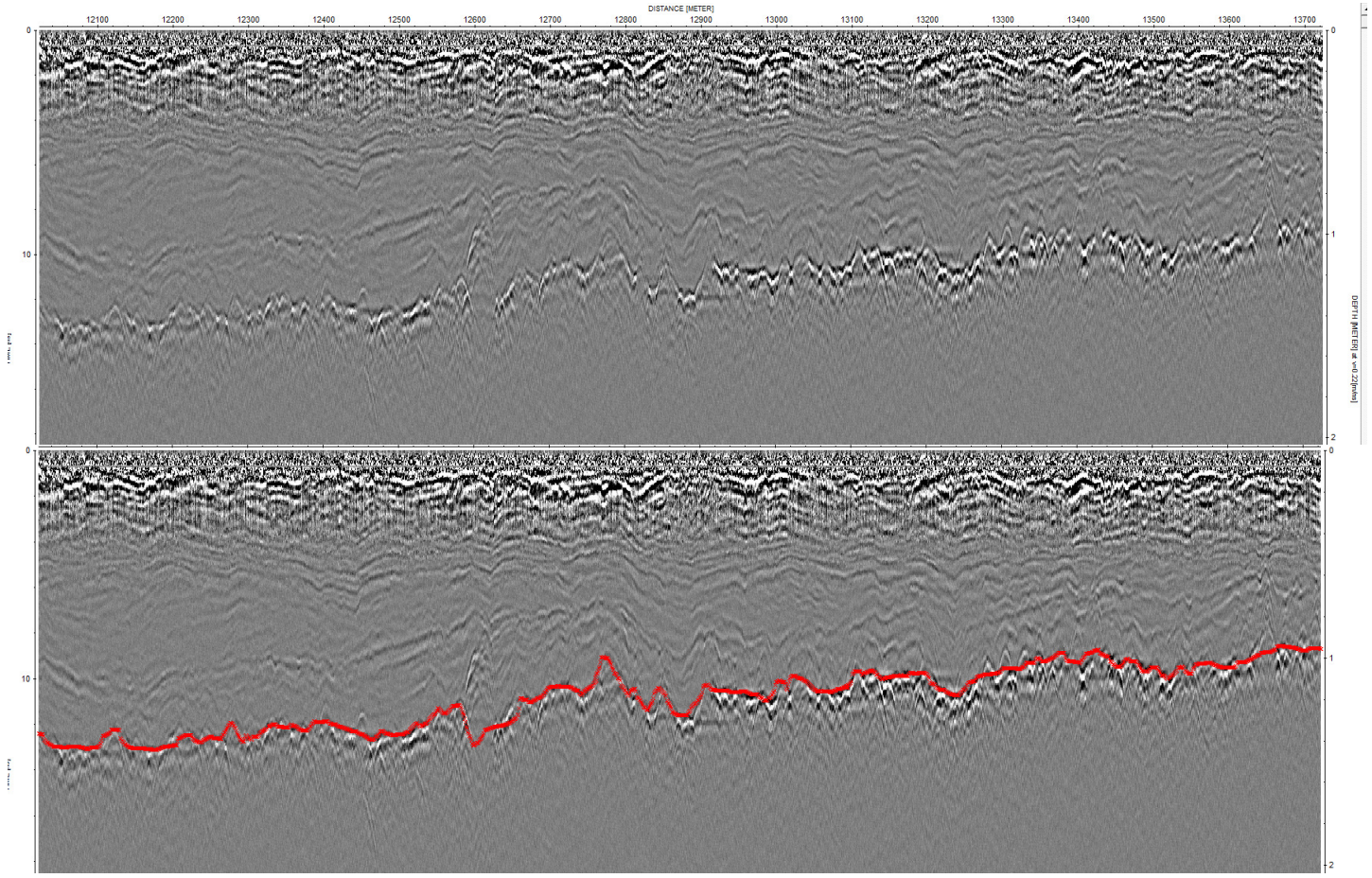
Theo Barnhart, Uni. Colorado
Francis Bliven, NASA WFF
Ty Brandt, UCSB
John Burkhart, Uni. Oslo
Christopher Crawford, Uni. MD
Tri Datta, Columbia Uni.
Roger De Roo , Uni. Michigan
Jeffrey Deems, NSIDC
Havard Erikstrod, Uni. Oslo
Peter Gadomski, CRREL
Arthur Gelvin, CRREL
Nancy Glenn, Boise State Uni.
Katherine Hale, Uni. Colorado
Christopher Hiemstra, CRREL
Brent Holben, NASA GSFC
Keith Jennings, Uni. Colorado
Richard Kelly, Uni. Waterloo
Jason Kraft, NASA GSFC
Alexandre Langlois, Uni. Sherbrooke
Hans-Peter Marshall, Boise State Uni.
Daniel McGrath, Colorado State Uni.
Chelsea Merriman, Boise State Uni.
Noah Molotch, Uni. Colorado
Mohammad Mousavis, Uni. Michigan
Anne Nolin, Oregon State Uni.
Walt Peterson, NASA MSFC
Chris Polashenski, Dartmouth College
Mark Raleigh, Uni. Colorado
Karl Rittger, Uni. Colorado
Chago Rodriguez, Boise State Uni.
Alexandre Roy, Uni. Sherbrooke
McKenzie Skiles, Utah State Uni.
Eric Small, Uni. Colorado
Lucas Spaete, Boise State Uni.
Marco Tedesco, Columbia Uni.
Chris Tennant, Berckley
Aaron Thompson, Uni. Waterloo
Liuxi Tian, Uni. Texas
Zach Uhlmann, Boise State Uni.
Ryan Webb, Uni. Colorado
Matt Wingo, NASA MSFC
…

… and even more contributors who helped pulling radars, carrying gear to the field,

and all the **transect, snowpit, and snow microstructure (SSA, SMP, snow cast) teams**
who collected the necessary in situ data to support the ground-based remote sensing activities

Ground Penetrating Radar

R. Webb, N. Molocth, D. McGrath, K. Hale



Stats:

81 transects

5 independent grids

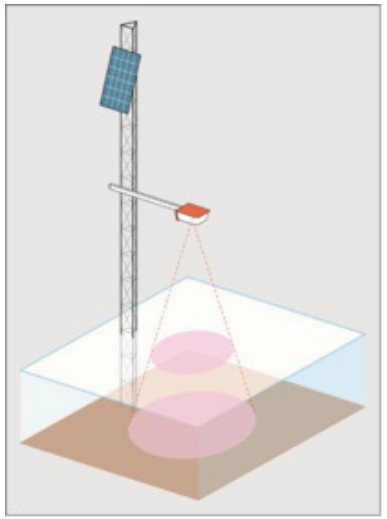
4 grids co-located with trenches

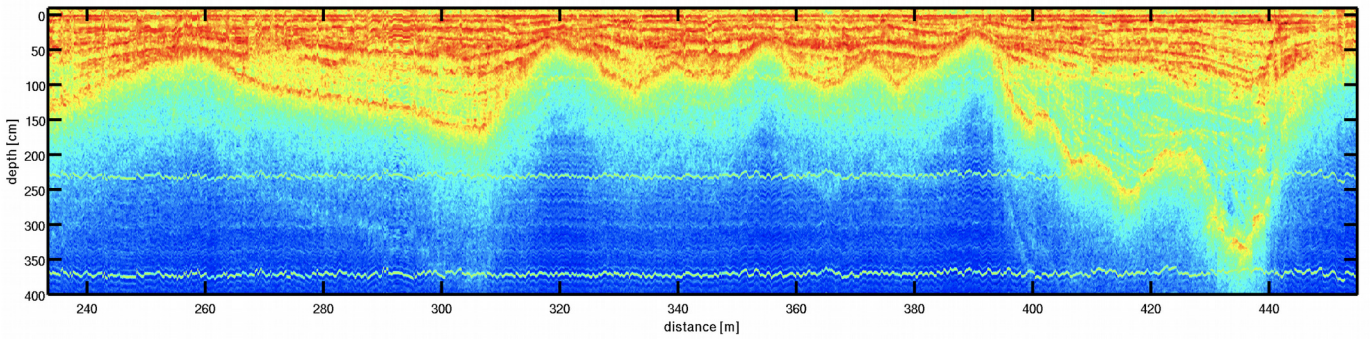
3 grids within TLS sites (K, F, J)

Boise State Uni. – Microwave Radars

H.P. Marshall, A. Gleason, C. Rodriguez, M. Robertson, D. Roberts, A. Odiaga

- Continuous tower-based GPR: Grand Mesa & Senator Beck LSOS
  - Frequency range: 1-6 GHz, impulse, downward looking
  - Estimates of SWE, snow depth, stratigraphy, LWC
  - Measurements every 15 minutes, October-April, 2017
- Continuous tower-based FMCW: Grand Mesa & Senator Beck LSOS
  - Frequency range: 24-25.5 GHz, upward looking
  - Sensitive to snowfall rate and precip phase
  - Measurements every 15 minutes, October-April, 2017





- Mobile ultra-broadband FMCW: Grand Mesa & Senator Beck sites
  - Frequency range: 6-18 GHz, downward looking
  - Estimates of SWE, depth, stratigraphy, 100 Hz
  - Integrated survey-grade (cm) GPS
  - *Hiemstra Spiral* surveys
  - 10 total days @ Senator Beck, 3 total days @ Grand Mesa

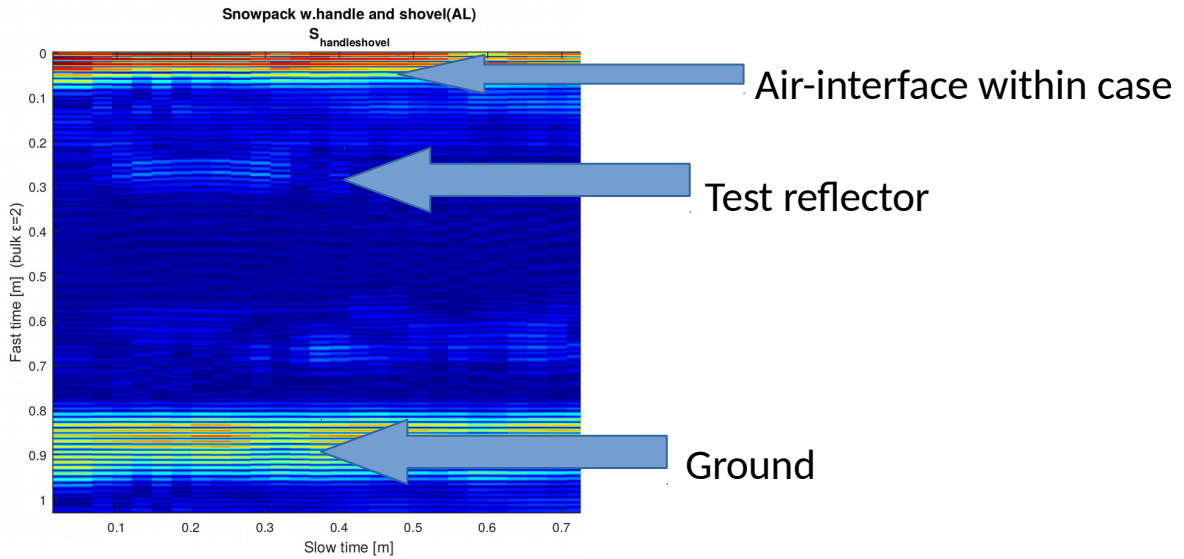
UiO Stripmode SAR Radar

J. Burkhart, J.H.H. Eriksrød

Preliminary results of strip-mode SAR results:

- 10 pits were scanned during the campaign
- Able to recover profile of reflector in snow pack
- Further processing required to correct for time/depth relations
- Sensitivity and resolution for 2 m. dry snow pack is good, need to explore Norwegian packs.
- SnowEx validation / coordination will be important in development of image/signal processing routines.
- Interested in collaboration, contact John Burkhart

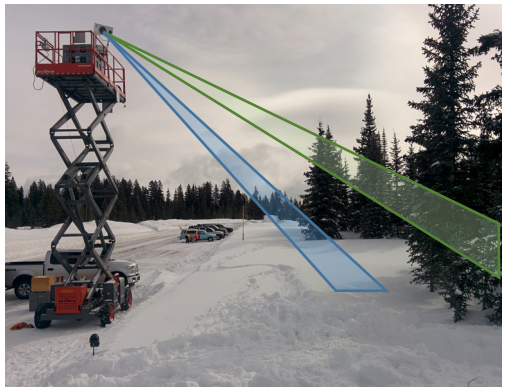
- Overall promising!

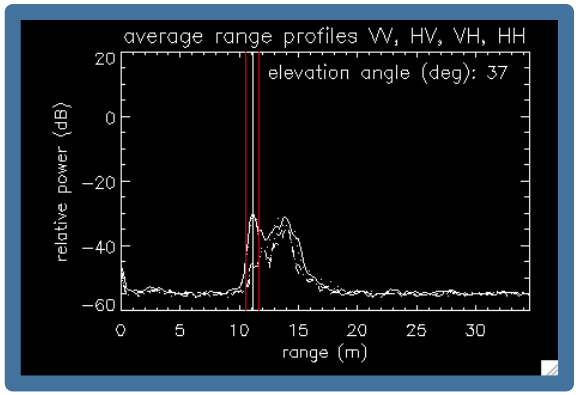


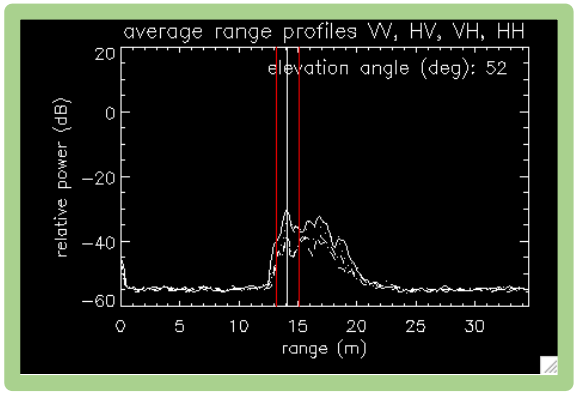
University of Waterloo Scatterometer

R. Kelly, A. Thompson

- Ku & X-band ground-based Scatterometer
- Measurement Sites:
  - 1 at LSOS (beside U of M radiometer truck)
  - 5 on the mesa (tree-free snow)
  - 2 at the County line pullout on skyjack (snow on mature conifers and adjacent vegetation-free snow)
- UWScat Scans:
  - 60° degree azimuth sweep (variable), 25° to 65° in elevation
  - Dual frequency, VV, HH, VH, HV
  - Open snow, forest snow and buried corner reflector experiment
- Adjacent snowpit & SSA measurements (including SMP): superb data set to explore snow around wooded landscapes and deep snow UWScat response.
- Tree scan (very, almost too) early results from Ku (17.3 GHz) scatterometer:







Open snow impulse response (tight)

Tree canopy impulse response (spread)

Ground-Based GPS for SnowEx

M. Raleigh, E. Small

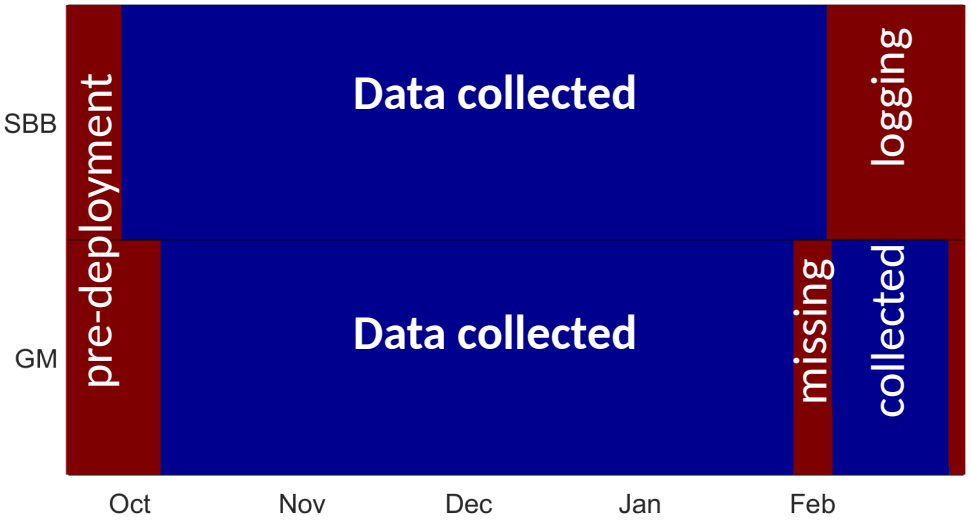
Grand Mesa - LSOS Ranger Station

Swamp Angel (Senator Beck)

Data processing for:

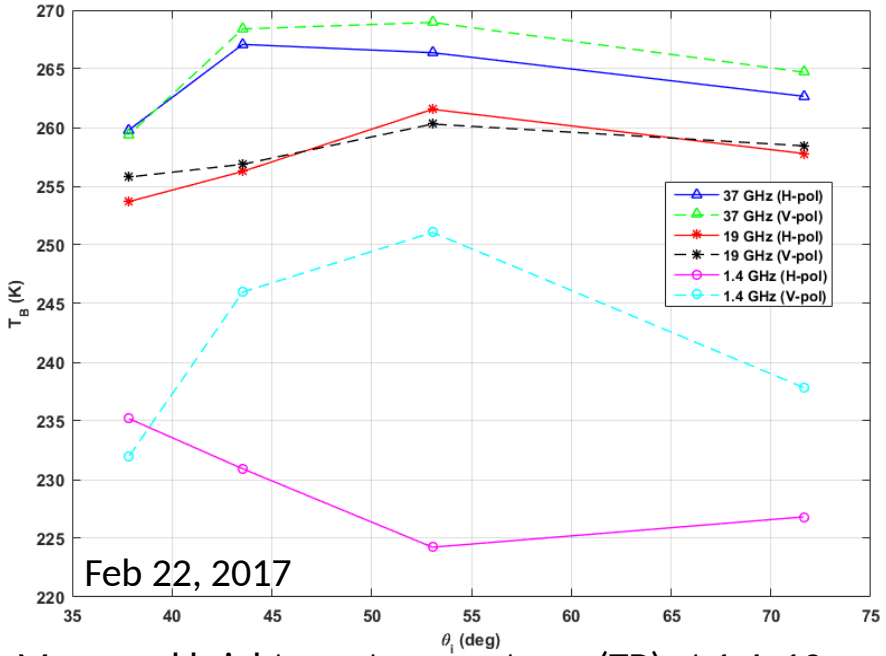
- Snow depth measurement
- Base station (airborne products)

Manual data retrieval



University of Michigan Microwave Radiometer

M. Mousavis, R. De Roo



Measured brightness temperatures (TB) at 1.4, 19, and 37 GHz at both H- and V-polarizations of evergreen trees close together for different incident angles.

Photo mosaic of the microwave radiometer system mounted on the boom truck.

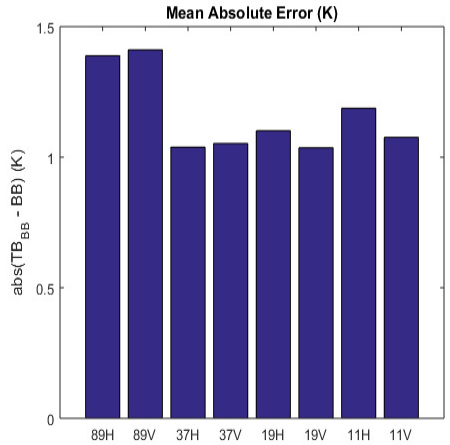
- Six different targets: gravel pad, rocky area 1, lone tree, rocky area 2, bunch of Evergreen trees together, and Aspen trees.
- Each target was measured at three/four different incident angles.
- Campaign was from Feb 06 to Feb 24, 2017 [day-of-year (DOY) 37 to 55]
- Measurements were collected successfully on 13 days out of the whole 20 days.
- Six clear sky calibrations as well as 4 microwave absorber calibrations were made.

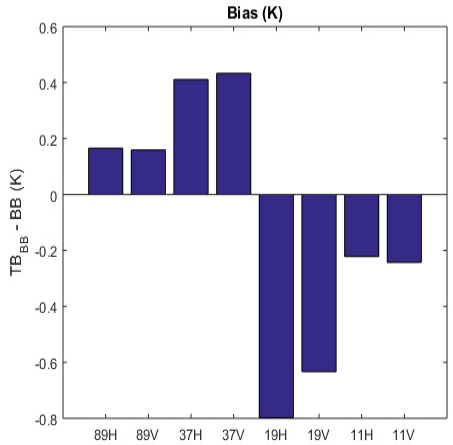
Surface-based radiometers measurements

A. Roy, A. Langlois

Measurements at 4 frequencies: 11, 19, 37, and 89 GHz

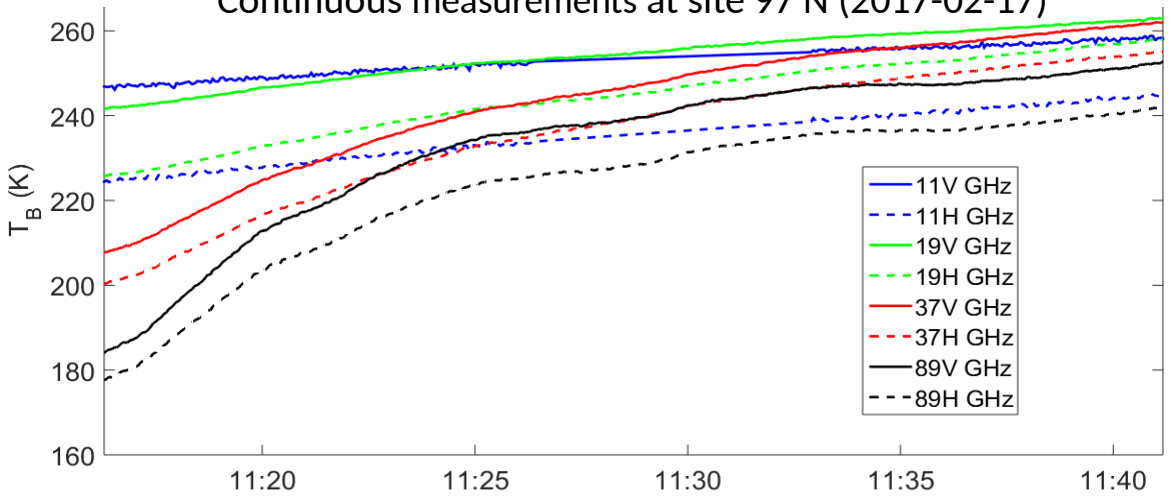
. 7 calibration checks with ambient black body
. 1 liquid nitrogen calibration
. Mean absolute error of ~1K





Location	# sites
LSOS	5
Grand Mesa	28 (3 short snowmelt time series) 13 SnowFork
Aspen Trench	5 (snow + veg.)
CountyLine (Lift)	3 (2 highs)
Spruce Trench	3 (snow + veg.)

Continuous measurements at site 97 N (2017-02-17)



- Strong brightness temperature increase related to surface snowmelt
- Stronger sensitivity at high frequencies (37 and 89 GHz) because of lower emission depth
- Signal seems to saturate quickly (20 minutes)

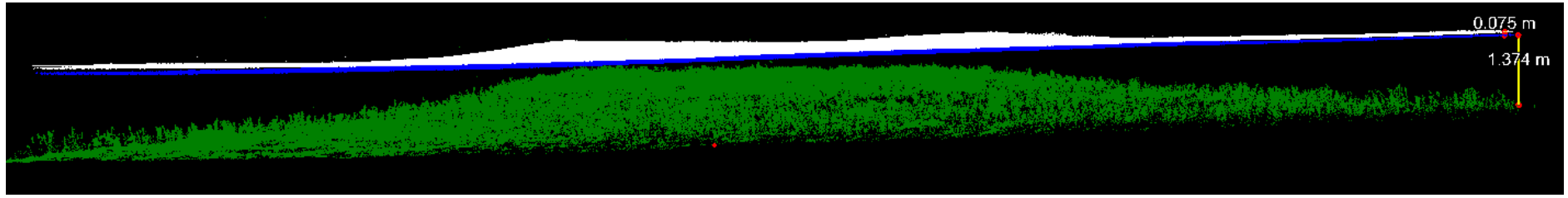
TLS – Boise State Uni.

N. Glenn, L. Spaete, C. Merriman, Z. Uhlmann, C. Tennant

Riegl VZ1000

TLS Site	Date	# of scans	Last scanned
Site K	2/8/2017	9	Fall 2016-BSU
Site P	2/9/2017	6	Fall 2016-BSU
Site L	2/10/2017	7	Fall 2016-Deems
Site F	2/21/2017	9	Fall 2016-BSU
Site K	2/22/2017	11	Fall 2016-BSU Feb 2017-BSU
LSOS-Cabin	2/23/2017	4	Fall 2016- CRREL Feb 2017-CRREL
Site J	2/24/2017	8	Fall 2016-Deems
Site O	2/25/2017	4	Fall 2016-BSU

Three dates of site K



TLS – CRREL Alaska Projects Office

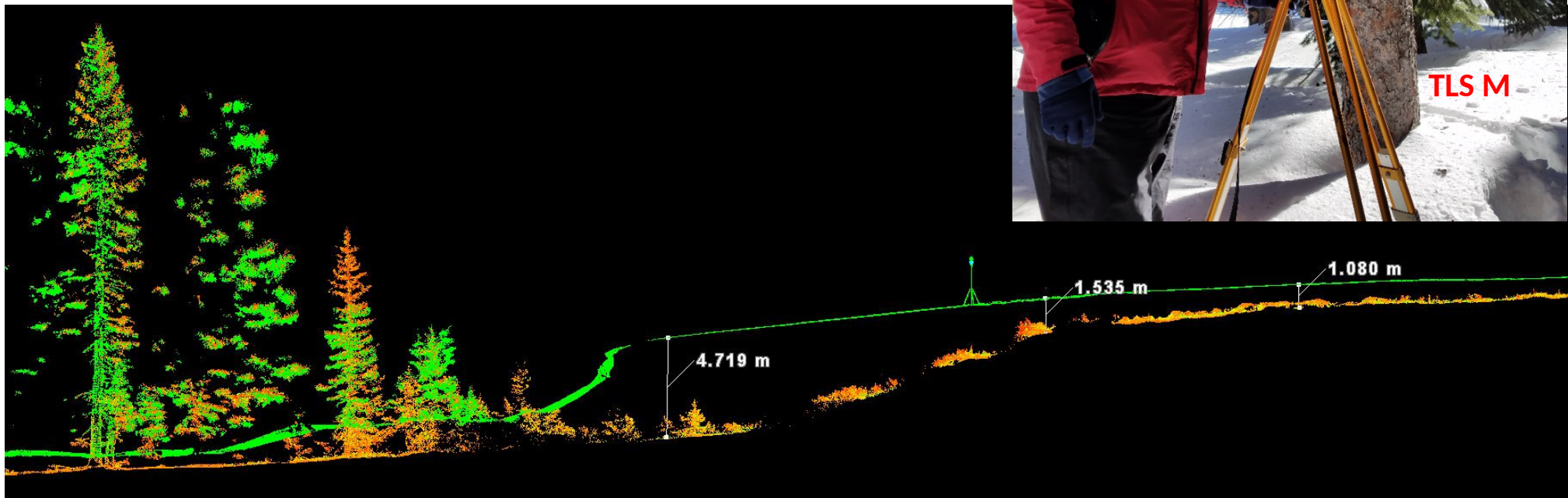
A. Gelvin, C. Hiemstra

TLS Location	Number of Scan Positions	Number of Points	Registraion Mean Absolute Error (m)	Date Scanned
Site D-1	5	19,680,000	0.005	8-Feb
Site A	11	109,670,000	0.012	9-Feb, 10-Feb
LSOS	5	42,800,000	0.011	13-Feb
Site M	9	75,400,000	0.012	14-Feb
Site N	10	71,540,000	0.010	15-Feb
Site D-2	4	19,300,000	0.006	16-Feb
Site B	5	23,500,000	0.005	16-Feb
Ranger Station	6	40,850,000	0.007	17-Feb
County Line	3	17,960,000	0.008	17-Feb

Leica ScanStation C10

Thank you
Manny Salgado
Carrie Vuyovich
Alex Studd-Sojka
Mary Jo Brodzik

TLS A
September (orange)
February (green)
deep drift cross section



ASD Transect Observations

C. Polashenski, K. Musselman, and Z. Courville

Photo: Travis Roth

-Spectral reflectance in open areas collected along transect lines at ~2.5m resolution on 2/8 and 2/9 with bare fiber/spectralon detector plate (pictured)

-2 open field transects collected

-Spectral reflectance in forested areas collected with repeat observations of snow surface over a sampling area of ~2m^2 using 8 deg FOV foreoptics, then placement of a spectralon sheet on snow surface and collecting same reflectance observations for relative reflectance.

- 3 partial forested transects collected

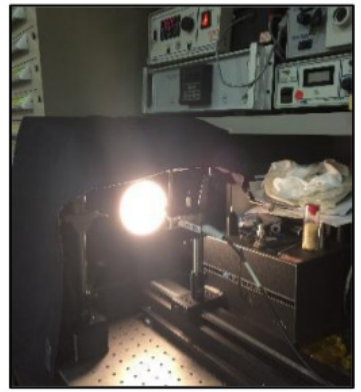
SnowEx 2017 ASD Spectrometer Cross-Calibration / Science Data Acquisition for Grand Mesa (POC: Christopher Crawford)

Objective: *To provide well calibrated in situ visible to shortwave-infrared (VSWIR, 350-2500nm) measurements for airborne validation and snow surface radiative transfer modeling*

(1) Radiance-based ASD Field Spectrometer Cross-Calibration using a NIST Traceable Source

(a) Pre-, in-field, post-laboratory Code 618 NASA/GSFC instrument assessments (*collaborator Milton Hom NASA/GSFC*)
(b) In-field instrument cross-calibration – NASA/GSFC and CRREL participation (*collaborator Chris Polashenski CRREL*)

NIST Traceable Source



(2) In situ VSWIR Spectroscopic Snow Surface Measurements

(a) Nadir snow surface reflectance transects – followed ASO protocols
(b) Snow pit bihemispherical reflectance (i.e., albedo) – followed ASO protocols
(c) Snow pit angular (0-60^0) hemispherical-directional reflectance factors (HDRFs)
(d) Snow pit angular (0-60^0) bidirectional reflectance factors (BRFs)

Snow transect set-up

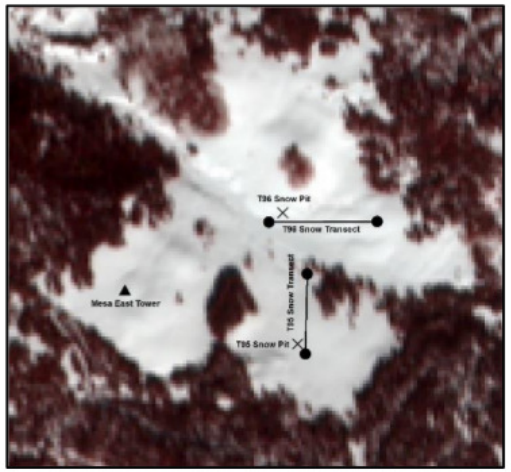
Snow pit set-up

Measurement Timeline

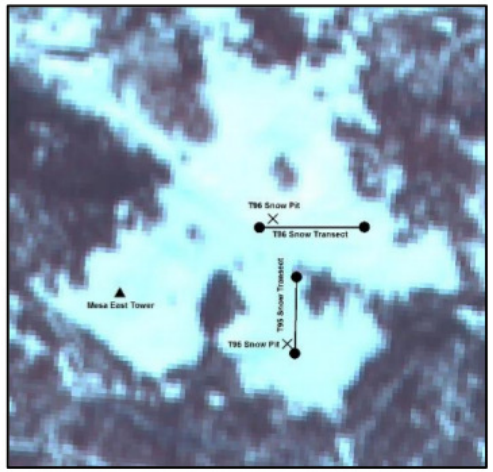
Feb. 14th – dry run on logistics and instrument protocols (no data)
Feb. 16th – blue-sky science data
Feb. 17th – blue-sky science data

Fun with snowmobiles!

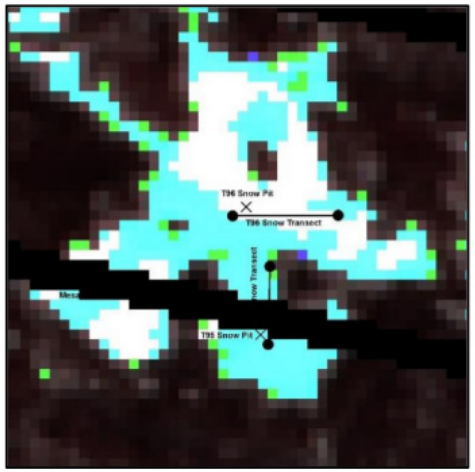
Sentinel-2A, Feb. 14, 2017
(UTC 18:04:31, Level-1C)



ASTER, Feb. 15, 2017
(UTC 18:07:26, Level-1T)



Landsat 7, Feb. 15, 2017
(UTC 17:52:00, Level-2 SR)



Contact Information
email: christopher.crawford.ctr@usgs.gov
phone: 605.594.2859

Albedo: Cosine Collector vs. a 360 Camera

T. Datta, M. Tedesco

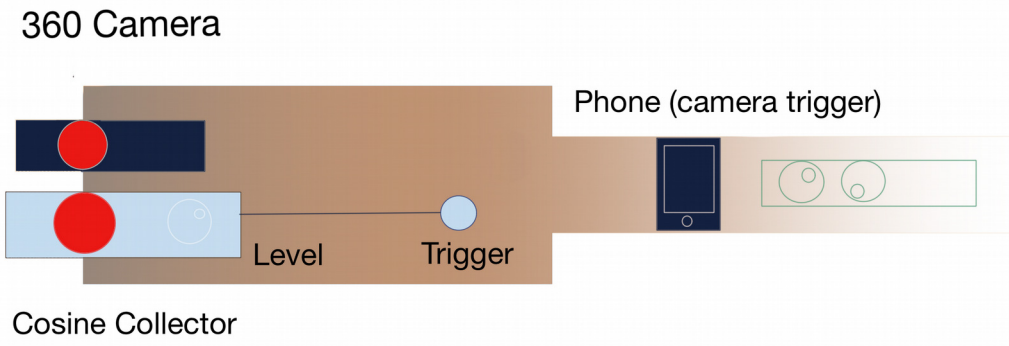
360 Camera

- upward and downward visible and NIR image (provides spatial variability)

+

Cosine Collector

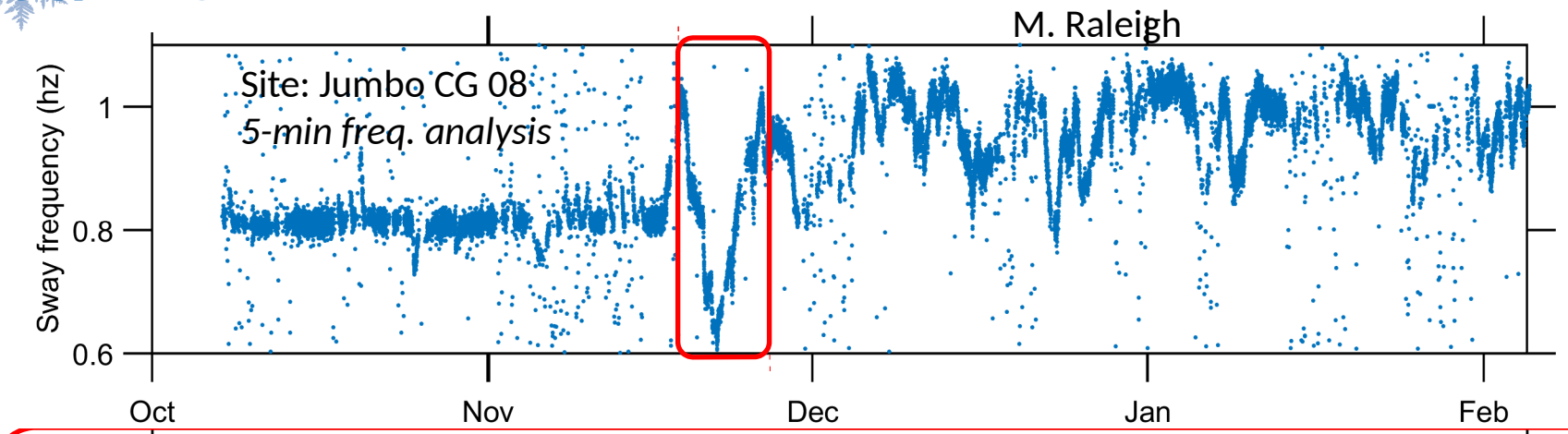
- For each wavelength, integrates a value over a hemisphere (plane)
- Albedo = ratio of the downward-looking measurement to the upward-looking measurement

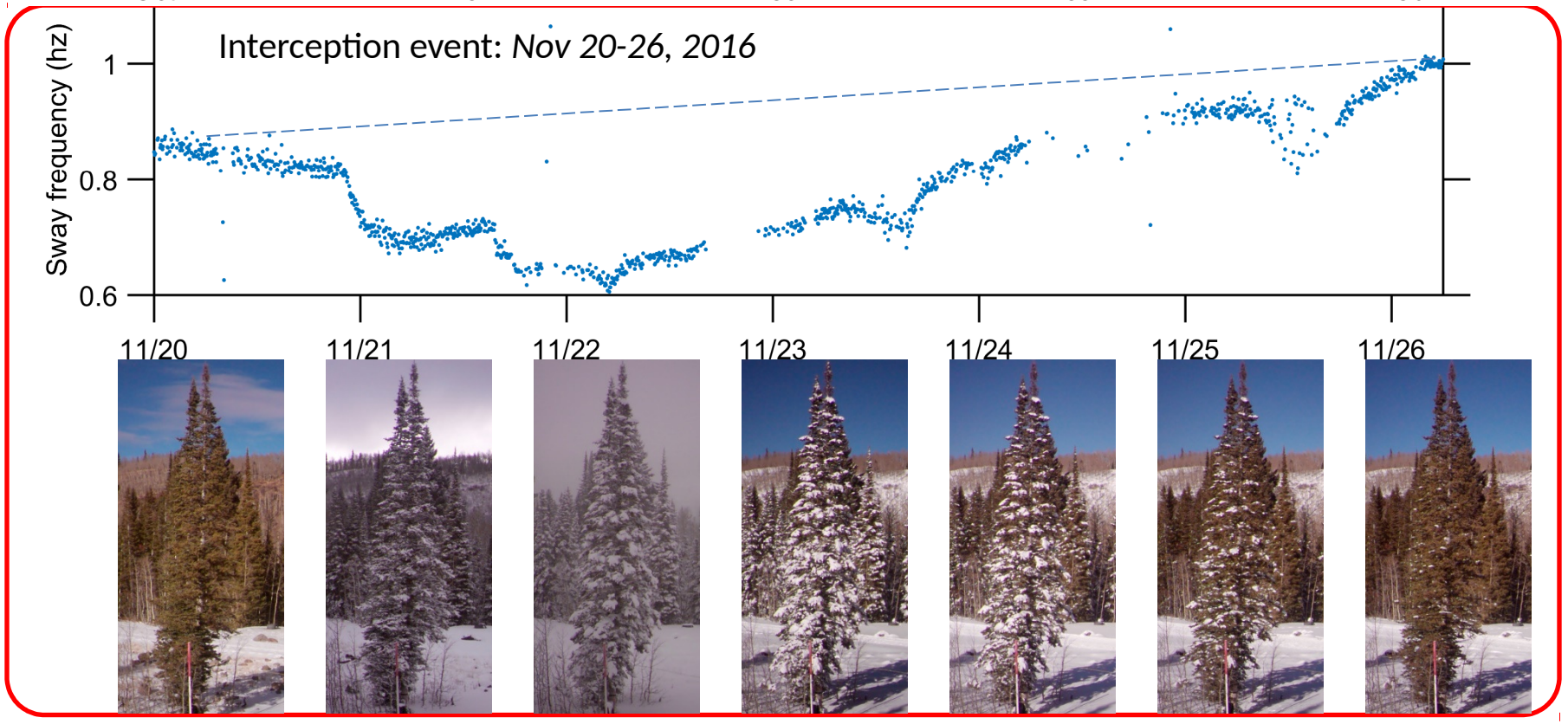


Snow depth sensors

K. Jennings, T. Barnhart, N. Molotch

Sway Frequency and Snow Interception





Initial results

Grand Mesa: 3 trees
Senator Beck: 2 trees

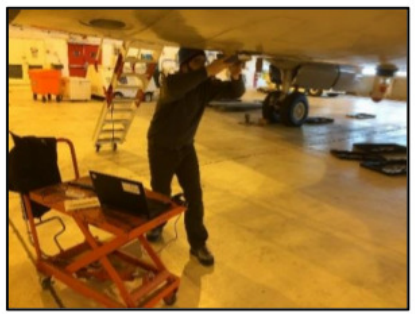
next steps:
temp. correction
convert Δsway to mass

SnowEx 2017 Thermal Infrared Calibration Overview (POC: Christopher Crawford)

Objective: *Develop an absolute thermal infrared (TIR) calibration for airborne and ground TIR measurements*

Laboratory Calibration

P-3 Cross-Calibration



Met Tower Cross-Calibration

Step 1: Develop an absolute TIR calibration using a NASA/GSFC Code 618 laboratory blackbody source and a well calibrated TIR sensor as the transfer standard (*collaborator Milton Hom NASA/GSFC*)

Step 2: Cross-calibrate the NRL P-3 TIR instrument suite using a field portable blackbody and the transfer standard TIR sensor (*collaborators Ed Kim, Eugenia DeMarco, Albert Wu NASA/GSFC*)

Step 3: Cross-calibrate Grand Mesa meteorological tower TIR sensors using the field portable blackbody (Everest Interscience source) and the transfer standard TIR sensor (*collaborator Paul Houser GMU*)

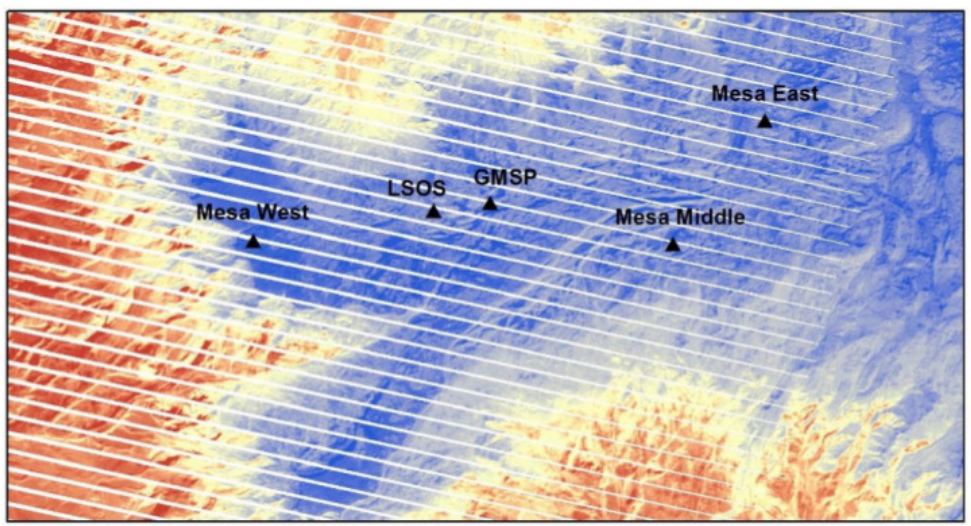
Feb. 15th – visited LSOS (~10am), Mesa West (~12pm), Mesa East (~2pm), and Mesa Middle (~4pm)

TIR Field Measurements:

(a) Skin surface temperature / blackbody temperature
(b) TIR sensor body temperature
(c) Blackbody incoming/outgoing longwave (8-14μm) radiation (W/m^{-2})

Contact Information
email: christopher.crawford.ctr@usgs.gov
phone: 605.594.2859

Landsat 7, Feb. 15, 2017
UTC 17:52:00, Level-1 Brightness Temperatures (Blue: Cold & Orange: Warm)



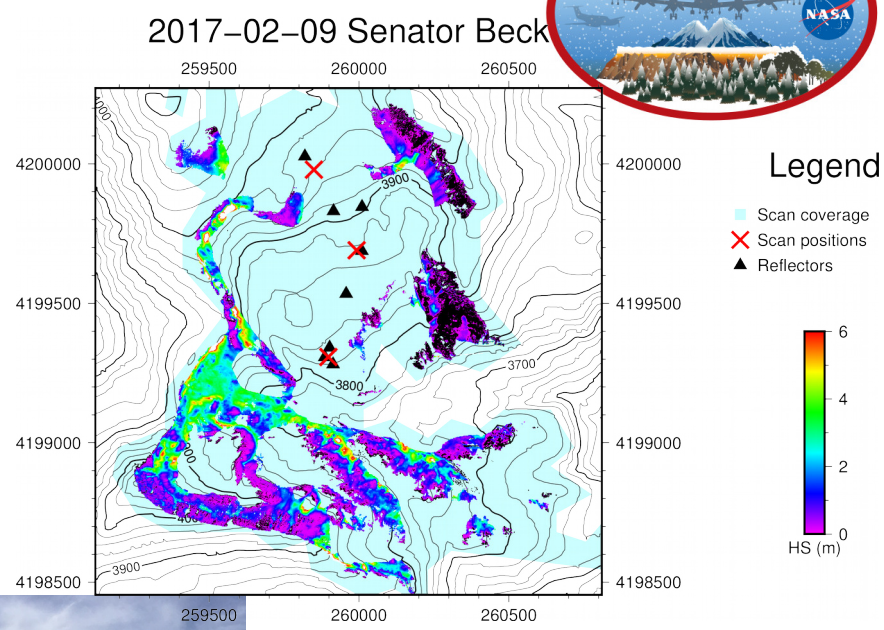
Senator Beck TLS

J. Deems, P. Gadomski, T. Brandt

Riegl VZ-4000 [1550nm]

Cylindrical reflectors for inter-scan registration and georeferencing via Trimble R10 GNSS receivers.

Date	Location	Points	Area (km²)
Feb 8	Swamp Angel	150 269 230	5.34
Feb 9	Upper Basin	100 512 763	5.85
Feb 20	Swamp Angel	146 990 278	5.43
Feb 21	Upper Basin	103 499 292	5.59
Feb 25	Swamp Angel	158 910 320	5.55



Senator Beck Spectroscopy – Week 1

K. Rittger

- Measurements
  - Albedo
  - Irradiance
- Locations
  - Swamp Angel Study sight
  - Senator Beck Study sight
- Observations dates
  - 2/8: Snow albedo measured slope normal and horizontal for 4 locations
  - 2/8: Irradiance prior to and during ASO flight
  - 2/9: Snow albedo measured on horizontal surface a 4 sites

Senator Beck Spectroscopy – Week 3

M. Skiles, J. Lund

Team: McKenzie Skiles and Jewell Lund
(University of Utah)

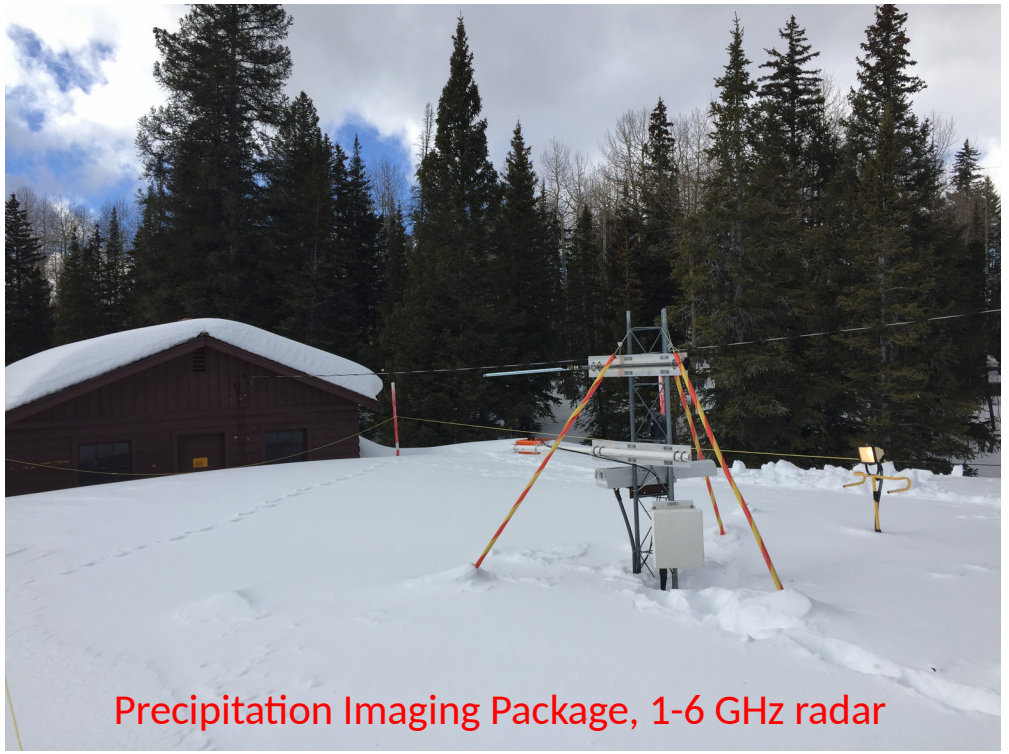
Instruments: ASD FieldSpec4 Full Range *(U of U)*,
ASD Handheld2 VIS/NIR *(JPL)*

Measurements

- Irradiance, 1x coincident w/ ASO overflight
- Radiance, 2x near coincident w/ overflight
- Albedo, 4x point measurements near instrumentation towers (qc'd, processed)
- Reflectance, 4x transect sets in low/mid basin (qc'd, processed through to grain size)

LSOS – Ranger Station

Weather station, precipitation measurements (radar, pluvio, and distro), GPS, sunphotometer



Precipitation Imaging Package, 1-6 GHz radar

Coordination among GBRS activities and between GBRS & in situ activities

Coordinated observations of:
. Snowpits
. Snow microstructure data (SSA)
. Snow MicroPenetrometer (SMP)
. Snow casts for micro computed tomography
. Radar (1-6 GHz)
. Radiometer (11, 19, 37, 89 GHz)

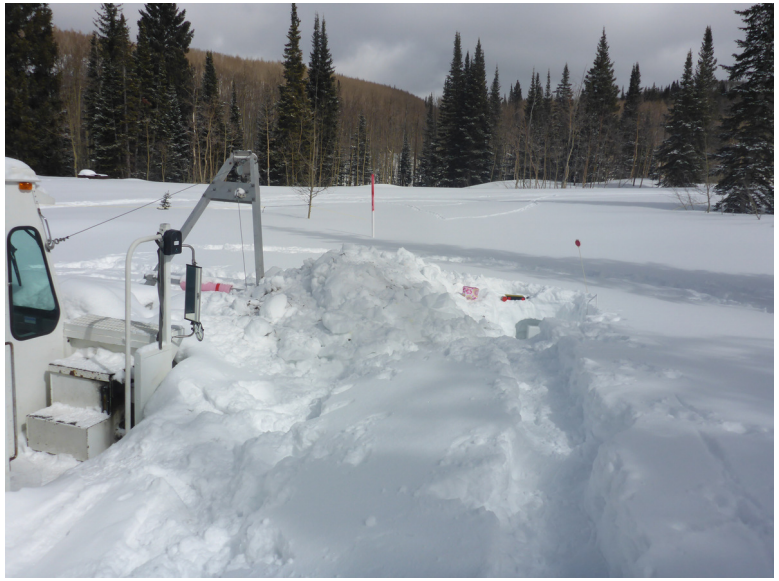
Coordinated observations of:
. Snowpits
. Snow microstructure data (SSA)
. Snow MicroPenetrometer (SMP)
. Scatterometer (X & Ku bands)
. Radiometer (1.4, 19, 37 GHz)

Coordinated passive microwave observations at different heights/scales, with:
. Surface based systems
. Truck-mounted systems,
. Airborne system (WISM, earlier in the month)

Coordination among GBRS activities and between GBRS & in situ activities

More microwave radiometric observations with snowpits and microstructure (SSA, SMP) observations at the same time

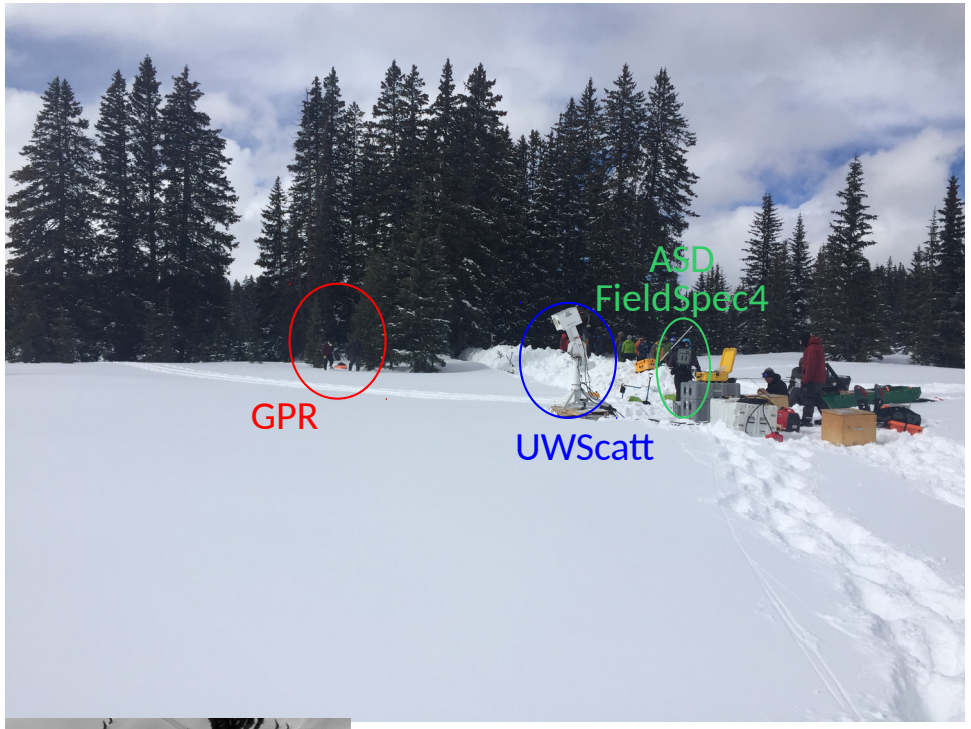
Downwelling microwave radiometric observations next to week 2 snow trench, during P-3 over flight

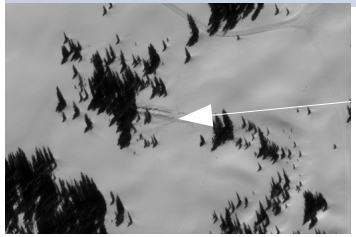


Snowpit and microstructure in the truck-mounted microwave radiometer field of view

Coordination among GBRS activities and between GBRS & in situ activities

UiO Stripmode SAR Radar
next to week 1 snow trench

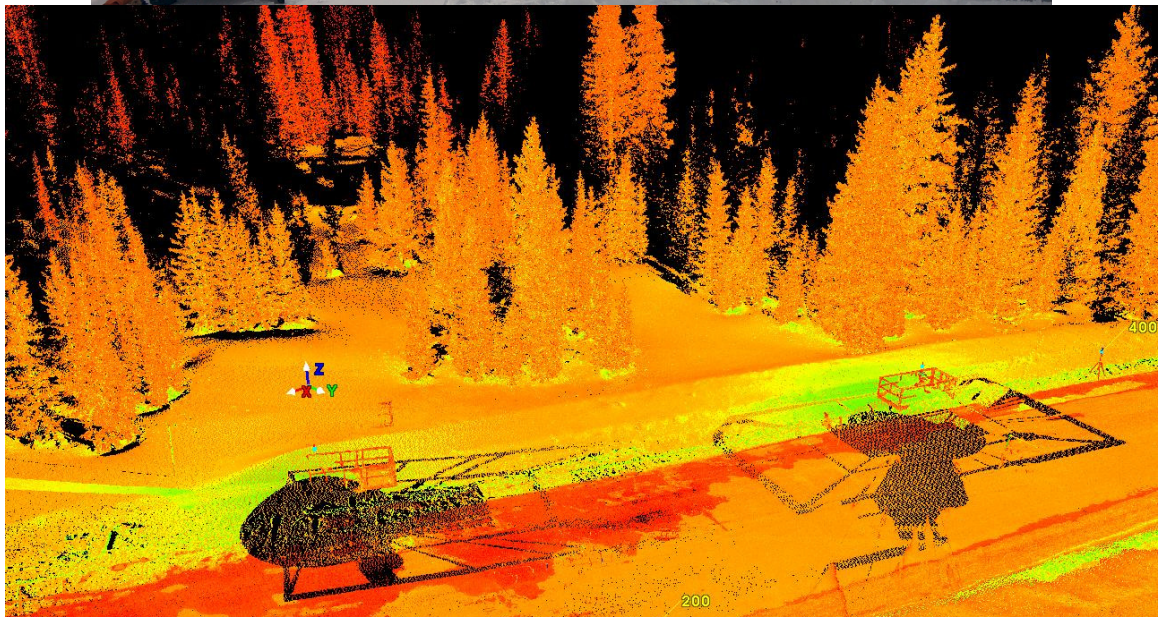


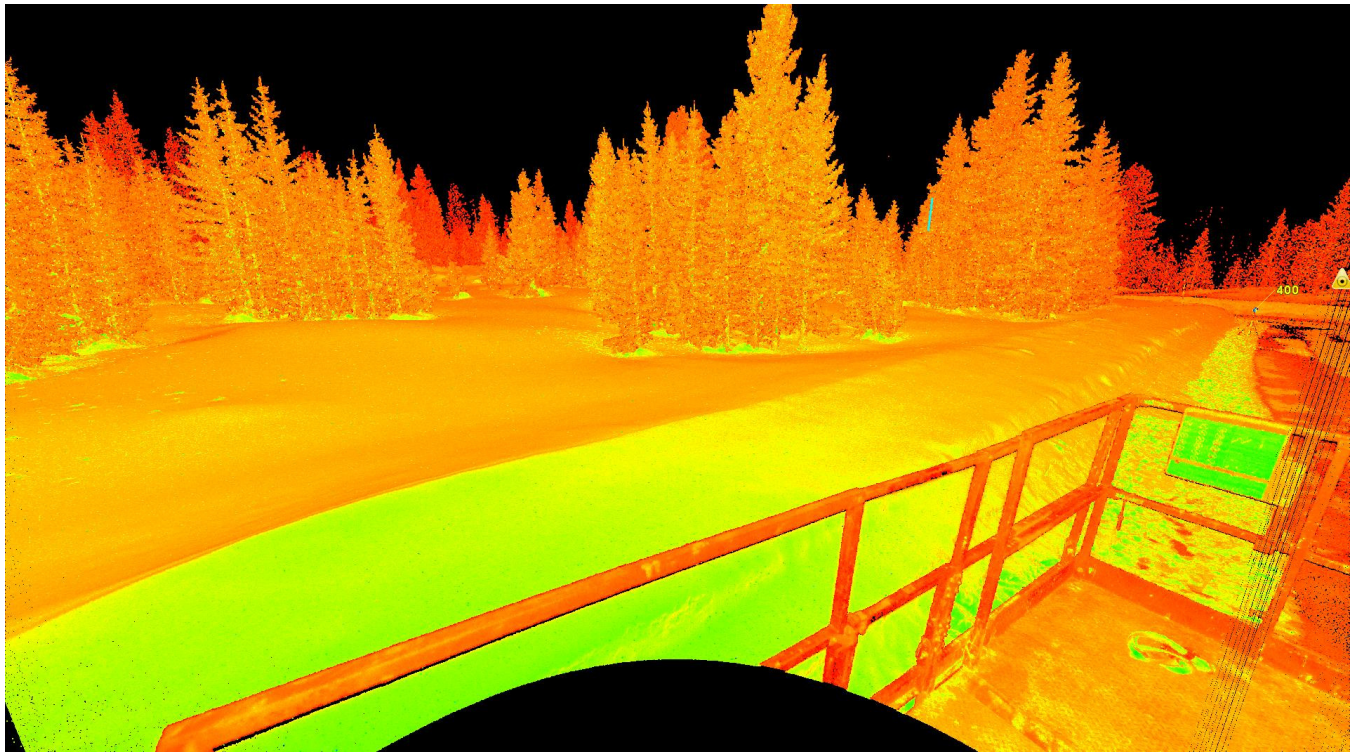


Radar, scatterometer, and spectroscopy next to week 3 snow trench (visible in World View 3 imagery)

GPR, UiO Stripmode SAR radar,
and dGPS location measurements

Coordination among GBRS activities and between GBRS & in situ activities





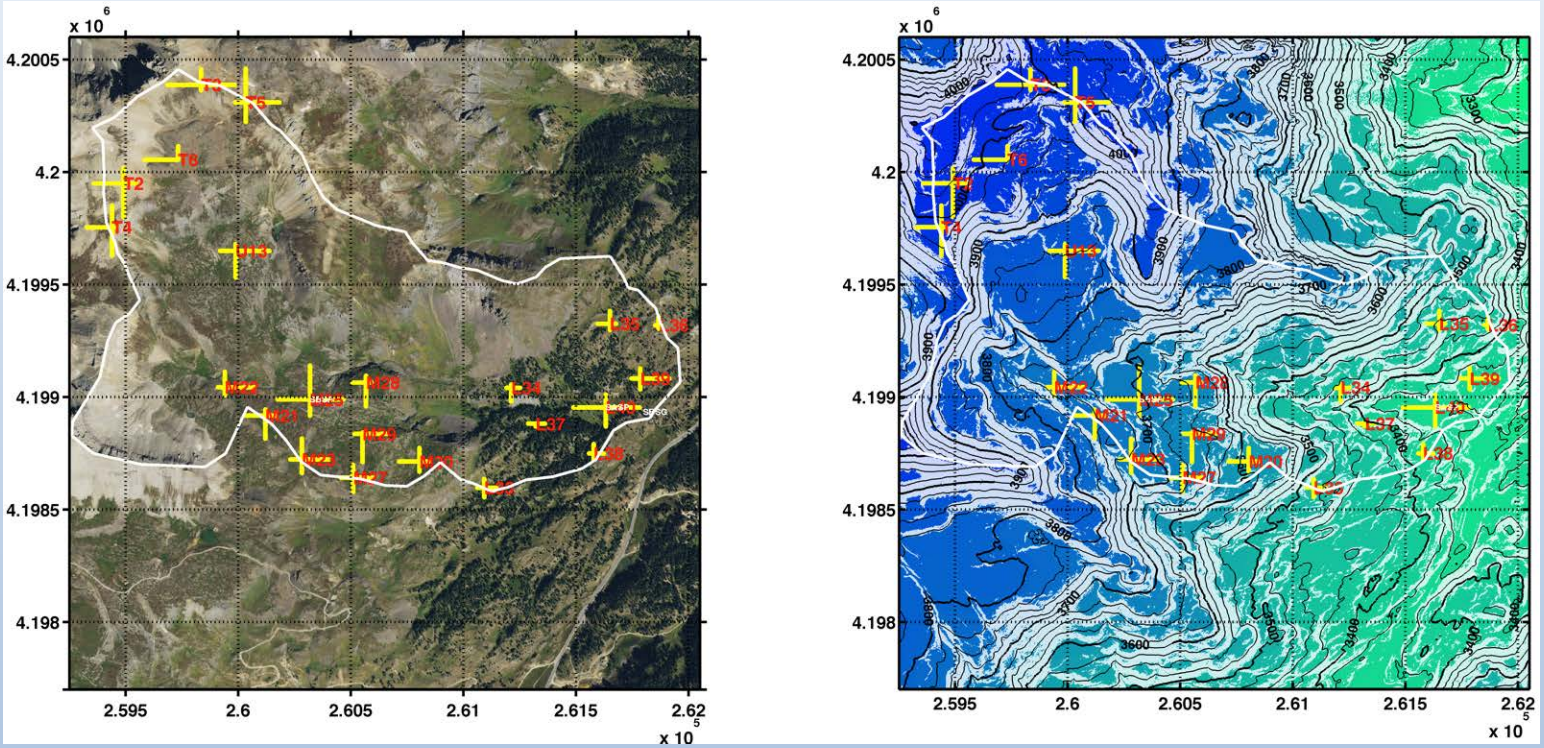
Lidar, radiometer, and scatterometer observations at several heights from a scissor lift, and one snowpit with microstructure measurements in week 3

Senator Beck

Senator Beck Basin – *SnowEx Site #2*

- H.P. Marshall, *BSU and U.S. Army CRREL*
- Andy Gleason, *Ft. Lewis College and Trautner*
- Jeff Deems, *NSIDC and WWA*
- Pete Gadomski, *U.S. Army CRREL*
- Andrew Temple, *CSAS*
- Chago Rodriguez, *Boise State Univ.*
- Ned Bair, *U.S. Army CRREL and UCSB*
- Karl Rittger, *NSIDC*
- McKenzie Skiles, *Univ. Utah and NASA JPL*
- Jewel Lund, *Univ. Utah*
- Gus Goodbody, *NRCS*
- Pat Kormos, *USDA*
- Andrew Hedrick, *USDA*
- Ty Brant, *UCSB*
- Jeff Derry, *CSAS*
- Mark Raleigh, *CIRES and CU*

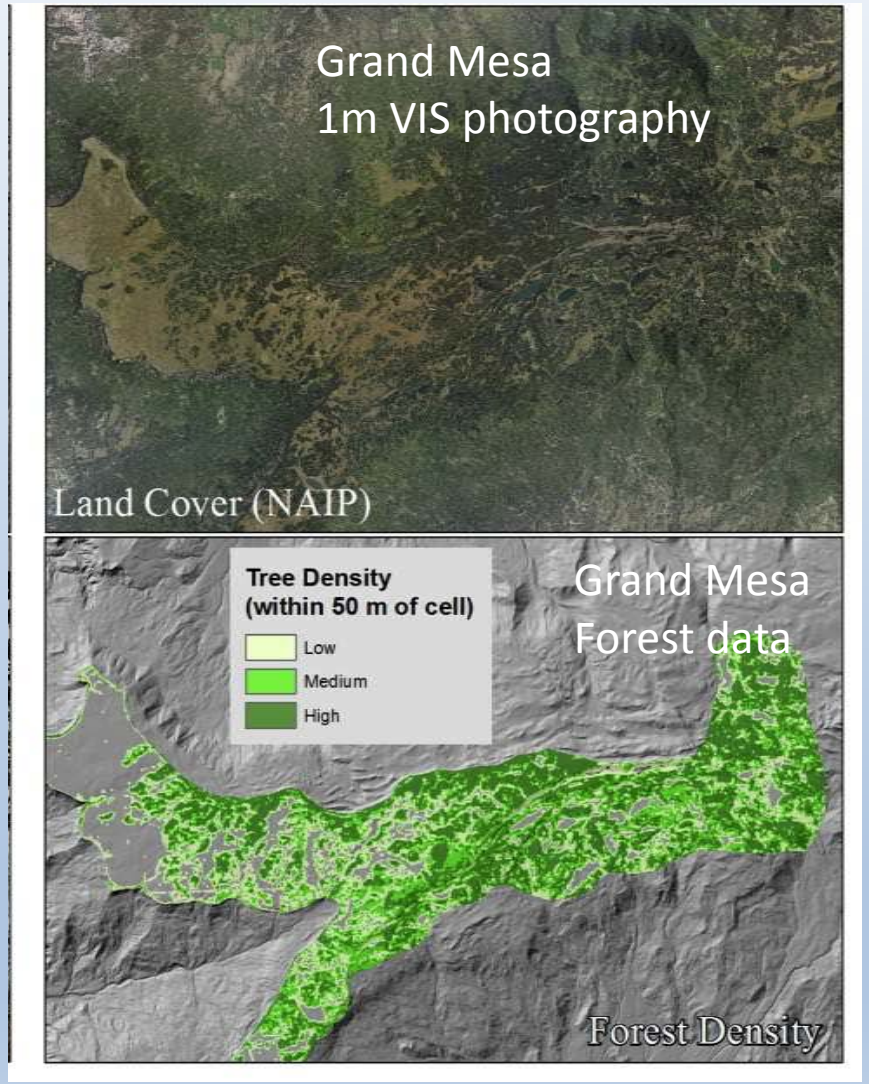
Senator Beck Basin – *SnowEx Site #2*

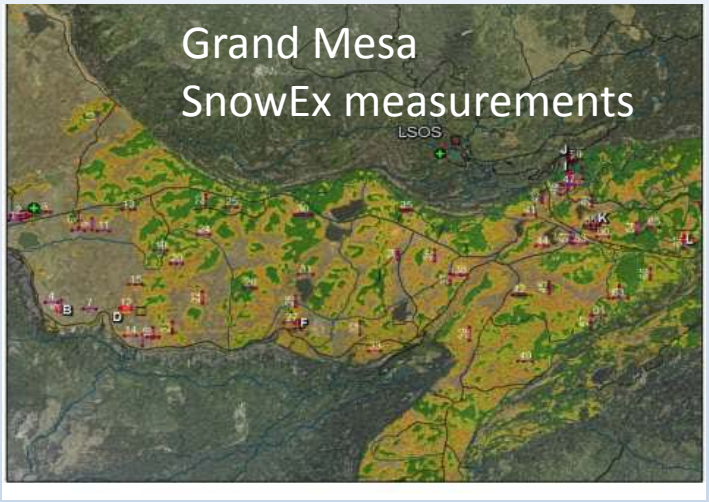


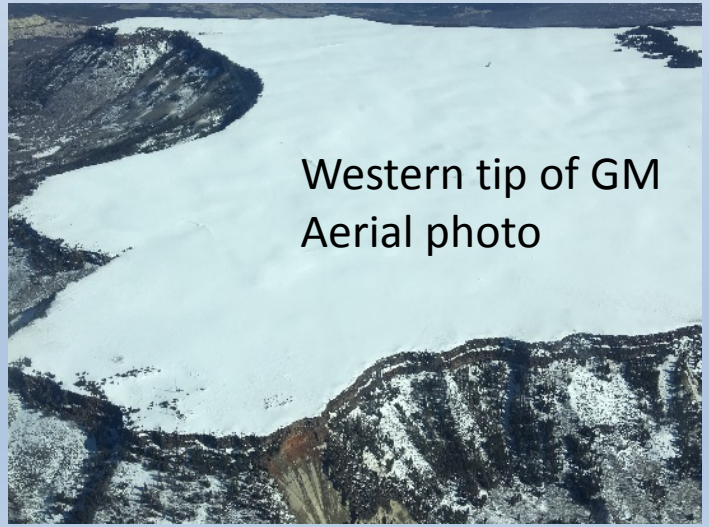
- Core measurements: same pit, transect protocol as Grand Mesa – Week 1 and Week 3
- Steep terrain, above and below treeline; avalanche hazard, visibility, exposure limited upper basin sampling
- GBRS - mobile: TLS, Spectrometer, FMCW radar
- GBRS – continuous: GPR, FMCW, GPS, timelapse cameras, tree accelerometers, sun photometer, 2 energy balance AWS
- Sampling performed throughout basin, covering range of elevation and vegetation, both weeks, with safety 1st!

Ancillary Data

Ancillary data of Sites-GM examples



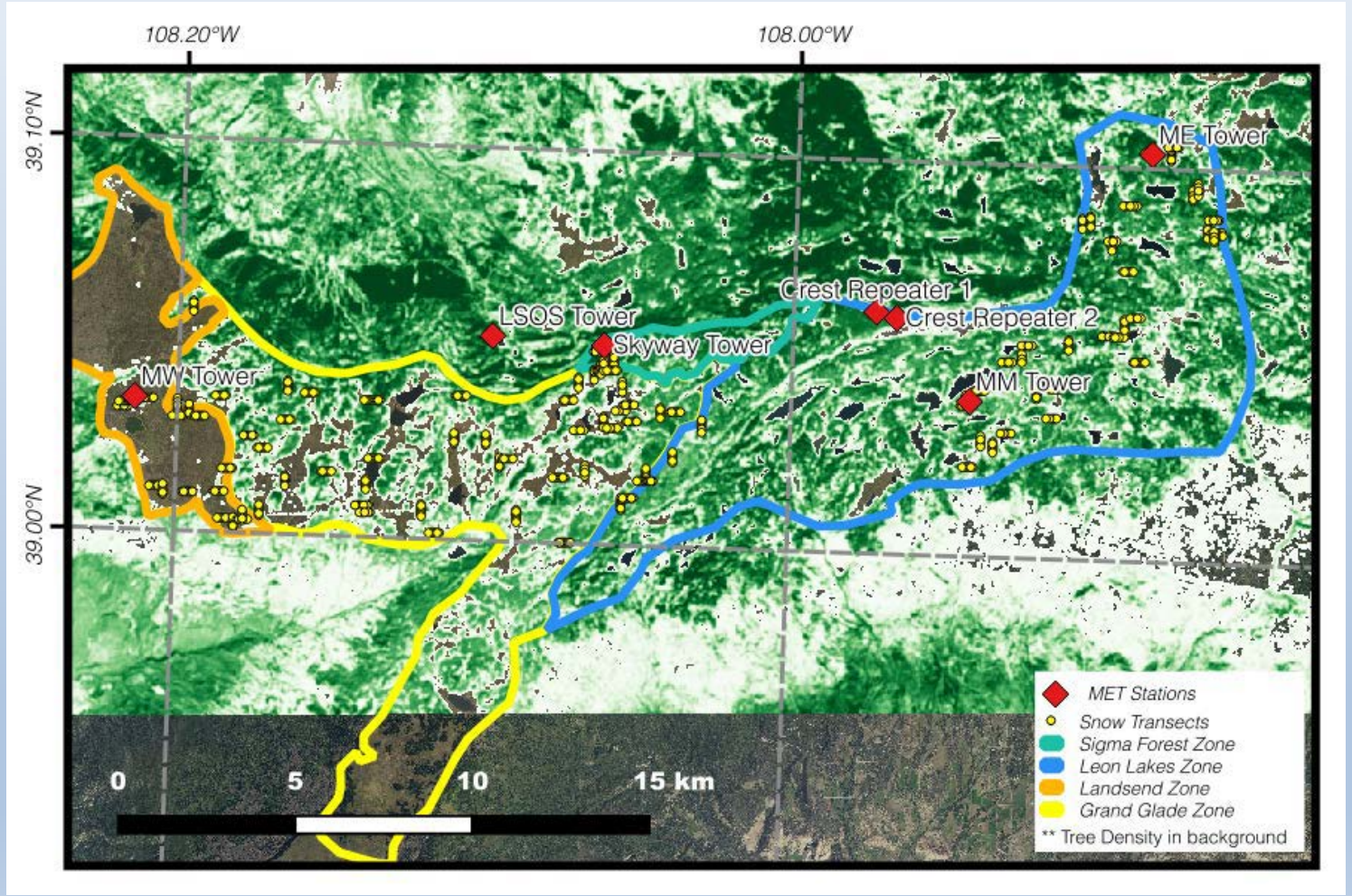




Met Stations

Grand Mesa Met Stations (5)

2 met stations in SBB were also augmented



Typical Met Instruments

ME Tower (20ft)

- Lat: 39.10374
- Lon: -107.88448
- Elev: 3078m
- 1X Campbell CR6, 10s sampling, 10min and hourly sample, average, max, min, standard deviation
- 3X Stevens HydraProbe II soil moisture sensors (-5cm, -20cm, -50cm)
- 4X Apogee IR radiometers (2X Nadir, 30deg N, 30deg S)
- 2X RM Young 05103 wind sensor (12ft, 20ft)
- 2X HC2S3 temperature/humidity sensor (12ft, 20ft)
- 1X SR50A sonic snow depth sensor
- 1X CNR4 4 component net radiometer
- 1X CS106 barometric pressure
- 25 node soil/snow thermocouple string (300,275,225,175,150,125,100,75,50,40,30,20,10,5,2.5,0,-2.5,-5,-10,-20,-30,-40,-50cm)
- 1X RF451 radio modem
- 1X time-lapse camera, 3hr

Daily Wx Forecasts

- Tailored forecasts provided by NWS office in Grand Junction (thank you!)
- Both aviation and surface forecasts
- Used for daily fly/no-fly decisions and ground activity safety considerations
- Archived on SnowEx webpage

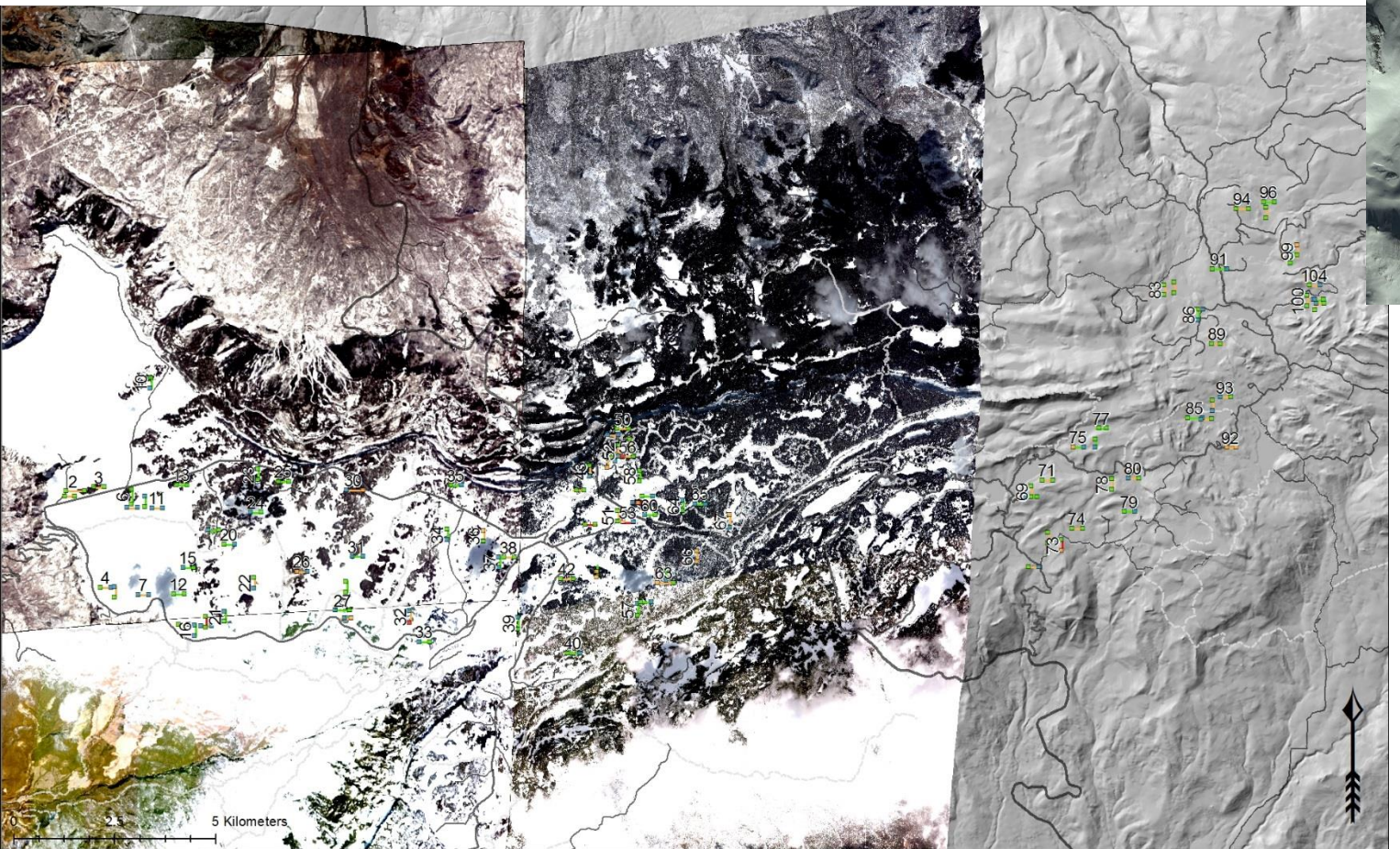
Satellite Data

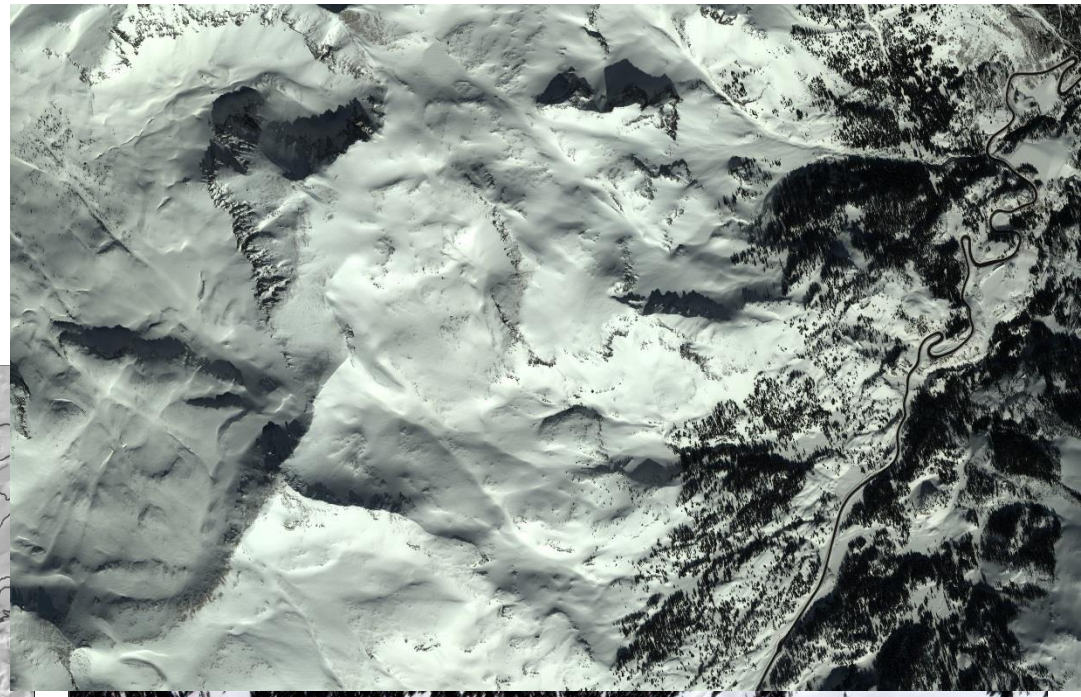
2017 Snow-On High Resolution Stereo Imagery (WorldView 3)

D. Shean, J. Lundquist, & C. Hiemstra

Grand Mesa
27 January 2017
1 February 2017
26 February 2017
18 March 2017

Senator Beck
8 February 2017
20 February 2017





Press Coverage

- 2 Press Days held
  - Grand Mesa
  - Peterson AFB
- >35 media interviews (27 TV, 7 radio)
- 8 national and top 15 markets
- Facebook Live & other social media products
- Blogs

- Many videos are available on the webpage, including downloadable broadcast-quality files
- If you use any for press purposes, please contact our SnowEx Communications leads
- patrick.lynch@nasa.gov
- rani.c.gran@nasa.gov

Data Delivery & Schedule 1

Data Provider Information Session

Thursday, 27 April 2:00-3:00 EDT

- NSIDC will provide an overview of:
  - Data file requirements and best practices
  - Process for submitting data and documentation
  - Description of the documentation and metadata needed
  - What to expect after you deliver data

- The resources and the workflow presented will be made available through the NSIDC SnowEx Website

Data Delivery & Schedule 2

- In pre-campaign data surveys, instrument leads indicated a 1-6 month range for delivery of data products to NSIDC
- NSIDC will work with the data provider to publish products as the are received, unless product prioritization is provided by SnowEx Leadership
  - Documentation and metadata must be provided before products an be published.

SnowEx Outreach – 2017

•23 – 28 April – European Geophysical Union, SnowEx Community poster using contributions from this webex (edited to fit poster!)

•6 – 8 June – Eastern Snow Conference, SnowEx overview

•May /June – submit article about SnowEx to AGU's Eos publication

•16 May – "Mini" session on GLAWEX at the International Association for Great Lakes Research (IAGLR), Detroit, MI – presentations by Dorothy Hall, Grant Gunn & Son Nghiem

•24 – 28 July – Special Session on SnowEx at IGARSS, Ft. Worth, TX – multiple presenters

•8 – 10 August – SnowEx Workshop on Preliminary Results, Longmont, CO

•12 – 16 December – AGU Special Session has been proposed, New Orleans, LA

Year 1 isn't over yet!

Still to come:

- Next few months: Data delivery (fall & winter deployments)
- Summer 2017: No-snow background flights w/SnowSAR
- Summer or fall: Site un-deployment (removal of items per agreement w/Forest Service)

Opportunities

- Currently-open THP ROSES call focuses on developing elements of a snow mission ATBD
- Recently-selected 'snow roundtable group' will develop THP's snow science and implementation plans, including where SnowEx years 3,4,5 will go & the foci
- 2nd Decadal Survey will contain snow advice (of course, the basic science questions, societal impacts, and options for mission concepts are already well-known)
- THP Snow Program Office at GSFC, led by Dorothy Hall. Assists THP PM (Jared Entin) on snow. You are encouraged to contact Dorothy about any THP snow matters!
- Comments from Jared

Year 1 Major Accomplishments (so far)

- Community building: ~100 participants from dozens of institutions trained & participated
- International participation
- 5 of 5 aircraft flown
- 9 of 10 airborne sensors flown
- 165 transects measured
- 154 pits measured
- 22 GBRS instruments
- 4 new met stations installed; 3 existing stations augmented
- No significant injuries
- Data to be archived at NSIDC
- Dozens of press reports, interviews, social media products, etc.
- Field site inventory, airborne lidar inventory
- Planned and executed in ~1 year

Concluding Remarks

- A giant “thank you” to all who helped make the Feb 2017 deployment safe & successful
- You, the “snow community,” showed that we can work together as a community and do some truly amazing things
- Imagine what you can do with the collected data; talk w/your colleagues; brainstorm how best to leverage the data to help achieve our goal of a global snow satellite mission
- If you’re a data provider, we’ll be in touch to work on data delivery; data webex on April 27, 2pm ET
- Check snow.nasa.gov/snowex periodically for updates